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Military Examples of Coastal Engineering

by Robert L. Wiegel, University of California

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Prepared for Coastal Engineering Research Board

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Contents

List of Figures

Preface

The military research and history described herein was presented at the 69th meeting of the Coastal Engineering Research Board (CERB) on April 14-16, 1999. Report preparation was conducted at the U.S. Army Engineer Research and Development Center (ERDC) Coastal and Hydraulics Laboratory (CHL), Vicksburg, MS, under CERB direction. Members of the CERB at the time of this report preparation were as follows: MG Russell L. Fuhrman, President and Director of Civil Works, U.S. Army Corps of Engineers; MG Jerry L. Sinn, Commander, U.S. Army Engineer Division, North Atlantic; BG J. Richard Capka, Commander, U.S. Army Engineer Division, South Atlantic; COL(P) Peter T. Madsen, Commander, U.S. Army Engineer Division, South Pacific; Dr. Robert G. Dean, University of Florida; Dr. Richard W. Sternberg, University of Washington; Dr. Billy L. Edge, Texas A&M University; and Colonel Robin R. Cababa, Executive Secretary, Commander, ERDC. This report was prepared by Dr. Robert L. Wiegel, University of California, Berkeley, CA. Dr. Todd Walton, ERDC-CHL, provided assistance in report preparation, technical editing, and review.

At the time of publication of this report, Dr. Lewis E. Link was Acting Director of ERDC, and COL Robin R. Cababa, EN, was Commander.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers

1 Introduction

Maritime ports and harbors are needed for many overseas military operations. Coastal engineering is required and integral in their design, construction, operation, and maintenance. For a major invasion and subsequent projected warfare operation, seized ports (such as Cherbourg, France, during World War II (WW II)) must be repaired, modified, and dredged (e.g., Buck 1948). Additionally, amphibious operations are an integral part of military (seizure or invasion) operations. It should be emphasized that amphibious military operations are not new. In his *The Histories*, Herodotus (1992, pp. 518-520) describes in detail the construction and use of the floating causeway (or bridge) across the Hellespont (the Dardanelles) by Xerxes in 480 B.C., its destruction by a great storm, and its replacement. Alexander also crossed the Hellespont, from Sestos to Abydos, in 334 B.C., but by ship—using 160 triremes (galley with three banks of oars) and a large number of merchant vessels to transport mounted troops and most of the infantry (Arrian 1958, p. 66). Information required for and lessons learned from United States (primarily) military amphibious and port operations will be discussed herein.

One of the first amphibious operations in America was the 49-day siege in 1745 of the French Fortress of Louisburg on Cape Breton Island, in what is now Nova Scotia, Canada (Buzzaird 1947). This was a successful joint Anglo-American operation by New England Colonists and the British Navy. Richard Gridley was the Chief Bombardier and Captain of Artillery, as well as the Chief Engineer of the operation. What is considered to be the first map made and published in America was Gridley's "Plan of the City and Fortifications of Louisburg" (surveys made in 1745) that shows the harbor, with soundings, some coastal features, the landing site, encampment site, the British Fleet and Transport anchorage, and locations of the batteries installed for the siege. In 1775, Gridley became the first Chief of Engineers of the "Grand Army," under George Washington, Commander-in-Chief.

There were amphibious operations during World War II in North Africa, Italy, France, and the Pacific involving Army Engineer Special Brigades, Marine Corps, and Navy Amphibious Forces (e.g., Anonymous 1946; Heavey 1946, 1947; Isely and Crowl 1951; Thompson 1996-1997), and some in the Korean War; and there were coastal engineering applications in port construction in Vietnam. A great variety of site conditions (tides, currents, waves, nearshore bathymetry, onshore topography, etc.) existed in these operational areas. Waves are a major factor in the behavior of landing craft, amphibian vehicles, pontoon causeways, pierheads, etc., but at the start of WW II, little was known quantitatively about waves in shallow water. Limited study had been made previously of waves and coastal

structures by U.S. Army Corps of Engineers (USACE) personnel in the 1880s, 1890s, and early 1900s. To the author's knowledge, the first book in the United States of America (USA) on waves and their effects on coastal structures was *Wave Action in Relation to Engineering Structures* by Captain D. D. Gaillard (1904). Gaillard was interested in measuring wave-induced forces and the characteristics of shallow-water waves, and stated:

> "As a rule an engineering structure subject to wave action is exposed only to the attack of shallow water waves; yet strange as it may seem, the number of recorded measurements of waves of this class is insignificant when compared with that of deep-water waves."

Despite Gaillard's comment, at the start of WW II, there was still very little known about shallow-water waves. The beginning of WW II was the start for major advances made in the measurement and understanding of coastal and littoral processes. Analysis capabilities and use of hydraulic models were improved considerably during the war years. Wave processes in shallow water are nonlinear and very difficult to analyze although at that time analyses of many processes were linearized to obtain useful (but often crude) estimates.

There is now routine use of coastal engineering knowledge developed during and after WW II (see *History of Coastal Engineering in the USA* by Wiegel and Saville (1996)). For the purposes of the present presentation, this experience is discussed within four main time divisions: WW II, post-WW II, Korean War, and the Vietnam conflict.

2 Amphibious Operations, World War II

World War II taught us that for an "over-the-beach" assault, details must be acquired of coastal type (for world maps delineating coastal type, see McGill 1959; Putnam et al. 1960), beach configuration, morphodynamics (large scale and small scale such as beach cusps and nearshore runnels), profiles (subaerial and nearshore—bars and troughs especially—including changes), wave conditions (offshore sea and swell, breakers, and surf), tides, beach material, beach trafficability, and nearshore and offshore bottom-holding capacity for moorings and anchored ships. As some of these are dynamic, forecasts of changes are needed. At the start of WW II, many charts were available to show areas safe for deep-sea navigation (e.g., U.S. Navy Hydrographic Office charts and British Admiralty charts), and there were large numbers of maps with details of land topography, but practically nothing of the nearshore zone, showing where or how assault troops and supplies could best be landed on hostile shores (National Research Council, Committee on Amphibious Operations 1951). For example, at the assault landing on Sicily, 10 July 1943, Combs (1944) states the following:

> "Buffeted by strong winds and high surf, the heavily laden troop and tank craft...[ran] aground yards offshore on the gently sloping beaches of the Italian island fortress. There as an easy target for enemy gunners they stuck fast, piled to the gunwales with valuable equipment... ."

This problem was overcome in time at Sicily by Allied forces using the newly developed Seabee "pontoon strings."

The types of military intelligence information required for amphibious assaults are listed in a report of the National Research Council (NRC) Committee on Amphibious Operations (1951, p. 15) and given herein as Appendix A. A great amount of information of this type was collected and evaluated during the war years by the U.S. Navy Hydrographic Office (Bates and Fleming 1947). Tidal information was available from both the U.S. Coast and Geodetic Survey and the British Admiralty. Some operations were at places where little data were available, such as Tarawa Atoll (Thompson 1996-1997, p. 16). To make use of data, coastal processes must be understood (i.e., wave refraction, wave diffraction, wave shoaling, wave groups, surf beats, wave runup and drawdown on the beach face, and wave-induced littoral currents (U.S. Navy, COMINCH 1945; O'Brien and Johnson 1947). Then data along with physical understanding of the coastal processes must be applied to calculate wave-induced forces on structures (breakwaters, pontoon causeways (Navy term, pontoon; Army term, ponton),

docks, landing craft), littoral currents (alongshore currents and rip currents) and estimates of their effects on equipment (broaching of craft and amphibian vehicles), sand transport (for example, relationship between bar depths and wave conditions, Keulegan 1945), and changing bottom bathymetry (effects on minefields, obstacles, pipelines). For details on state of the art in military coastal engineering at the end of WW II, see the *Manual on Amphibious Oceanography* (University of California at Berkeley, Institute of Engineering Research 1952).

Wave conditions at a landing beach are of prime importance to military amphibious operations. For planning and for operational wave forecasts, correlations among wind strength, duration, fetch, and wave height and period were developed in the USA and in the United Kingdom (U.K.). These procedures were then used in planning of operations (for the American procedure, see U.S. Navy Hydrographic Office 1943, 1944; Seiwell 1947; Bates 1949; Wiegel and Saville 1996; Thompson 1996-1997). The forecasting curves were improved in the decade following WW II; for example, Figure 1 (from Wilson 1966) presents the observational data of wind-wave parameters for conditions of unlimited duration in deep water, with wind velocity corrected to an elevation of 10 m. These wave-forecasting relationships became known as the SMB (Sverdrup-Munk-Bretschneider) curves. Morrough P. O'Brien (during WW II) suggested this form of dimensionless parameterization for the correlations (Wiegel and Saville 1996).

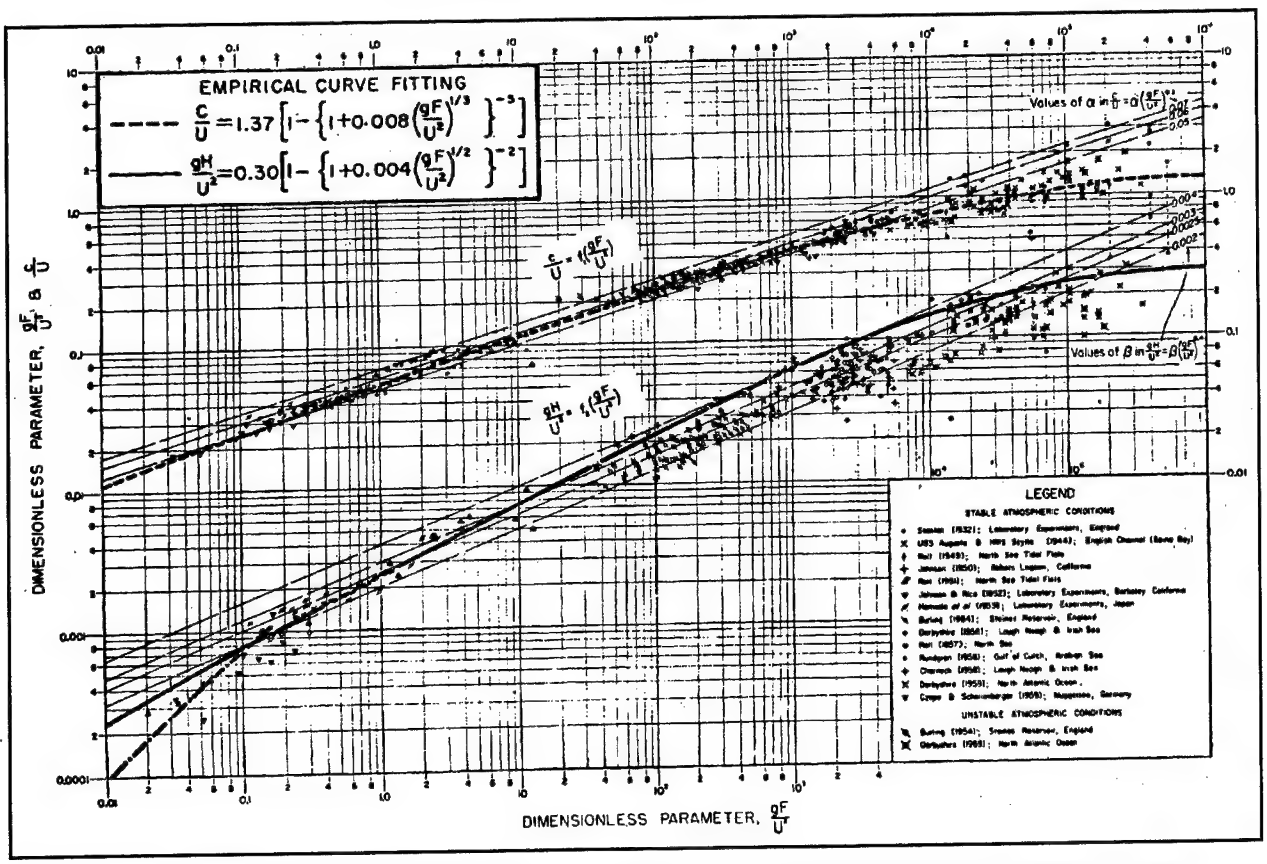


Figure 1. Observational data of wind-wave parameters for conditions of unlimited duration in deep water (wind velocity corrected to 10-m elevation) (from Wilson 1966)

During WW II, a number of military officers were trained in meteorology (the Navy term was aerology) at the University of California at Los Angeles (UCLA). A few were further trained in wave and surf forecasting during a 6-week program at the Scripps Institution of Oceanography (SIO), University of California, San Diego, by Professor H. U. Sverdrup and Walter H. Munk (Bates 1949; Thompson 1996-1997). For across-the-beach operations, the deep-water waves had to be transformed to surf, involving wave shoaling and wave refraction. Linearization was used, using monochromatic waves together with empirical approximations. According to Thompson (1996-1997, p. 13):

> "We learned how to forecast the dimensions of waves in the wind area where they are generated, how to forecast the dimensions and arrival time of swell at any location distant from the generating areas, and how to forecast breaker heights in the surf zone after waves have travelled from deep water offshore to the beach. The latter process involved the construction of wave-refraction diagrams that show how wave energy is amplified or diminished along the shore because of the nearshore bottom topography."

Reference to the refraction procedures can be found in Johnson, O'Brien, and Isaacs (1948).

The fact that waves behave differently for various bottom conditions was learned by experience. As an example, Warren Thompson, U.S. Navy beach and wave observer/forecaster, commented (1996-1997, p. 22) that while on a low-altitude reconnaissance flight over Peleliu, Palau Islands, on D-2 (13 September 1944):

> "Almost immediately I made the disconcerting observation that the incoming swell did not behave according to the wave forecasting rules I had been taught, which apply to waves shoaling over a gently sloping sea bottom. Instead, here the waves arrived abruptly at the reef from deep water, broke over the outer margin losing energy in the process, then reformed and traversed the shallow 300-500 yard-wide reef and broke a second time on the beach as smaller and much shorter waves having periods of one or two seconds....I handled this problem by using my forecasted waves only as a rough guide of what to expect, and relied primarily on my visual wave estimates and my judgment of the ability of amphibious vehicles to cross the outer reef margin and transit the reef to the beach."

Two examples of this type of wave transformation are shown in the photographs of Figure 2. Note multiple crests over the reef where the waves have been transformed by the wave-breaking process and reformation in shallow water. They do not have to break to transform over a reef, however; the author has observed this on occasions.

For practical use, it was necessary to relate what small-craft operators judged to be the wave height during an operation with what was shown on correlation curves. The term "significant wave height" was originally based on actual wave

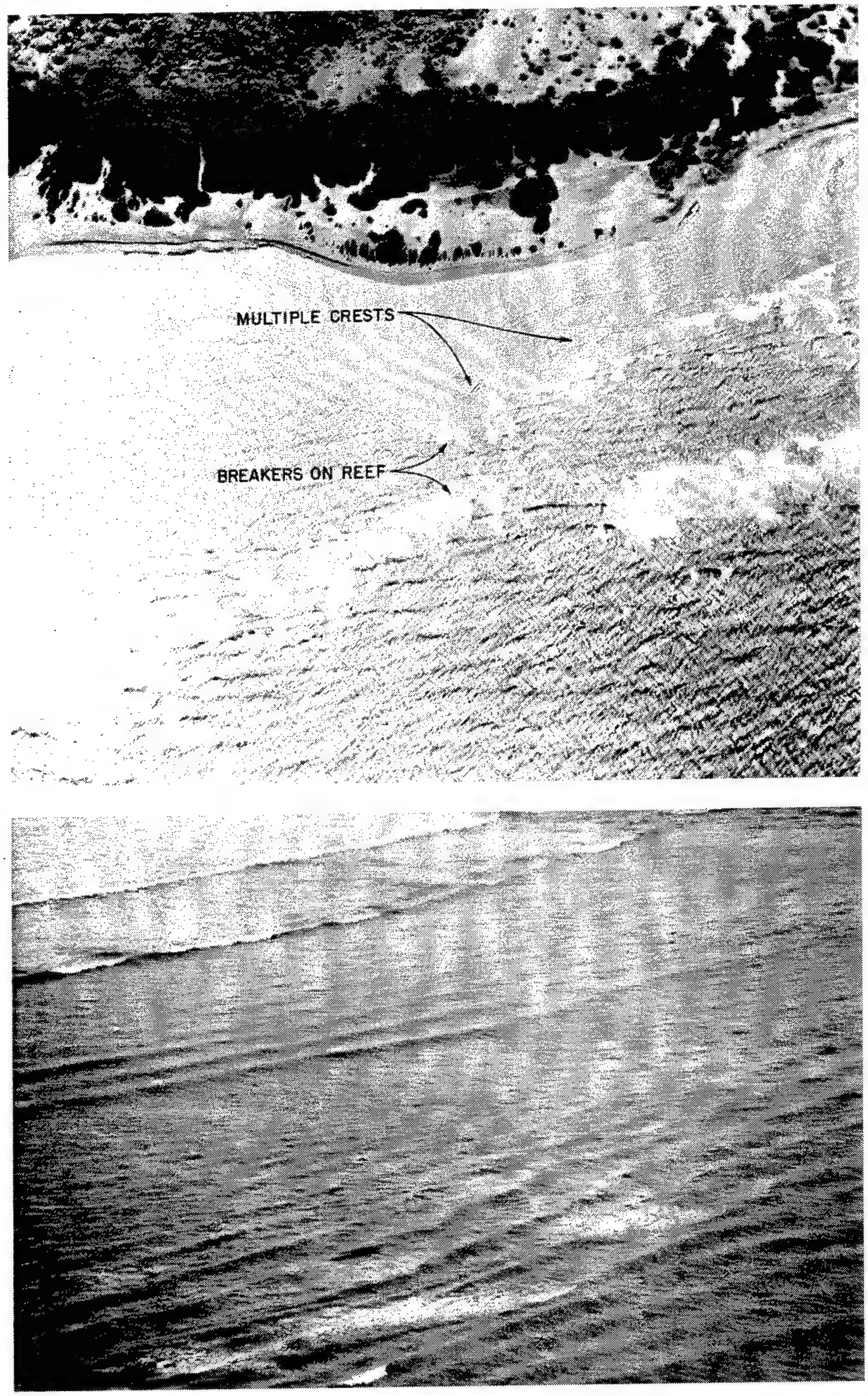


Figure 2. Waves over a fringing reef, multiple crests (top, by U.S. Navy; bottom, Princeville, Kauai, HI, 22 January 1992 by R. L. Wiegel)

heights, but is now more commonly related to the variance of wave record which is the integration of the wave energy spectra, all based on linearized analysis. It is interesting to trace the history of the term significant wave height. In the Normandy planning and operations, the term "predicted wave height" was used. Charles C. Bates (1949, p. 550; see Figure 3) states:

> "It was also necessary to determine how the height values extracted from generation graphs might be compared to observation which reported both average and maximum wave heights, particularly since the maximum height reported was often double that of the average height. It appeared that small craft operation was concerned neither with the occasional maximum wave nor with the average value, which is considerably depressed by the many small waves present in a wave train. However, a value half way between the average and maximum height appeared to be highly useful. This value, termed the "Predicted Height," was used for purposes of comparison. The value falls amazingly close to the "Significant Wave Height" defined by Sverdrup and Munk about a year later."

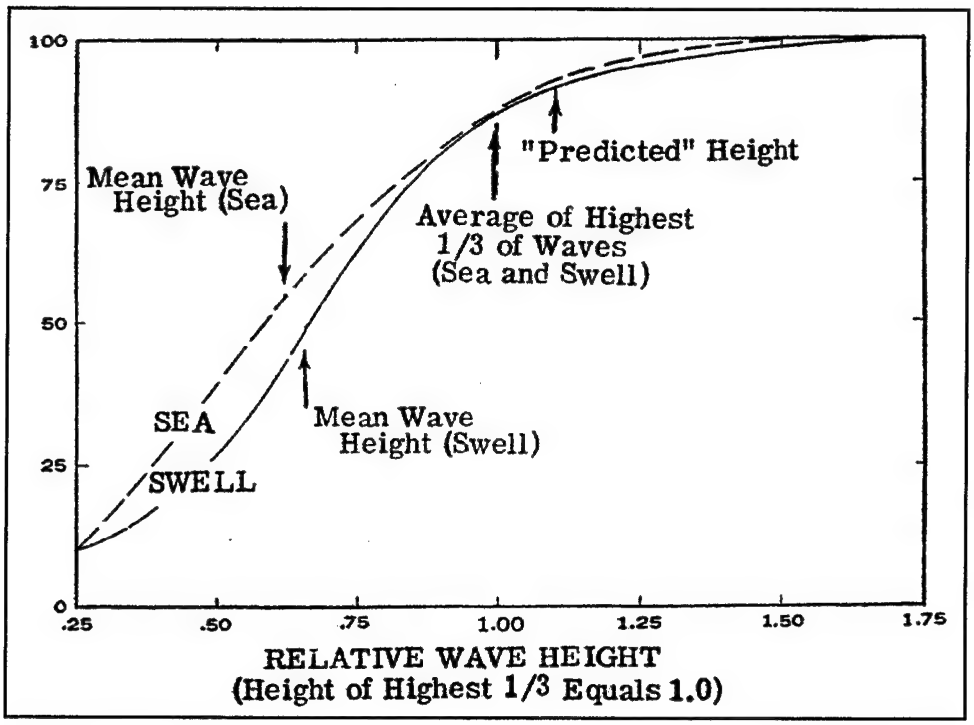


Figure 3. Percent of occurrence of relative wave height for sea and swell (after Scripps Institution of Oceanography's Wave Report No. 68) (from Bates 1949)

The author has been on hundreds of ocean beaches and rocky shores, in about 55 countries. Although coastal processes are general, their mix and environmental conditions are site specific. Inadequate knowledge of them for a civil project or military operation can result in great difficulties, and for an assault landing beach can be disastrous. The commando assault of Dieppe, France, on 18-19 August 1942 (Anonymous 1943, p. 136) provides an example of one such disaster:

"The fire on the beaches, however, as soon as they set foot on them, proved to be as fierce as ever. Some found cover behind stranded tanks, others in folds of the shingle.... A strong westerly set of the tide had taken more than half of them to the west of the Casino where they eventually got ashore, not on the main beach but on a small stretch of shingle and rock beneath high, unscalable cliffs. There they were cut off, for they had no room to deploy.... They eventually surrendered about noon, after more than a hundred had been wounded."

In addition to characteristics, processes, forcings, etc., more needs to be learned about the probabilities of occurrences of storms (joint intensity, duration, and frequency distribution, etc.) and the resulting waves and currents. These are needed for the risk analysis of an operation. Perhaps there is no better example of why this is necessary than the storm of 19-22 June 1944 along the coast of Normandy (e.g., Seiwell 1947). This gale blowing from the northeast generated waves that were larger than designed for. There was great damage to the artificial harbors, craft, and ships, and operations were disrupted and delayed. A map of the assault beaches is shown in Figure 4. The aerial photograph of Mulberry "B" Harbor at Arromanches, Figure 5, shows the sunken ship and concrete caisson breakwaters on the right and the "inner harbor" on the left, with pier heads and causeways. This undated photograph was taken after storm damage had been repaired. Eisenhower (1948, pp. 238 and 261) wrote:

"Construction of the great artificial harbors engaged the services of thousands of men and added indescribable congestion to already crowded ports and harbors."

"The Mulberry [an artificial harbor; see Manning 1944; Jellett 1948] at Omaha Beach in the American sector suffered damage beyond repair. Great numbers of ships and small vessels were grounded or hurled onto the beach... On the day of the storm's ending I flew from one end of our beach line to the other and counted more than 300 wrecked vessels above small-boat size, some so badly damaged they could not be salvaged.... There was no sight in the war that so impressed me with the industrial might of America as the wreckage on the landing beaches. To any other nation the disaster would have been almost decisive;..."

In his discussion of the Mulberry harbors (Institution of Civil Engineers 1948, p. 443), D. H. Little states:

"...at the end of that storm Mulberry A [at St. Laurent, "Omaha Beach"] ...was written off as a complete loss, and 50 percent of Mulberry B [at Arromanches] was lost..."

Jellett (1948, p. 304) wrote:

"The break-up of the St. Laurent Harbour in the gale of June 19 to 22 and its subsequent abandonment allowed the concentration of all resources at Arromanches."

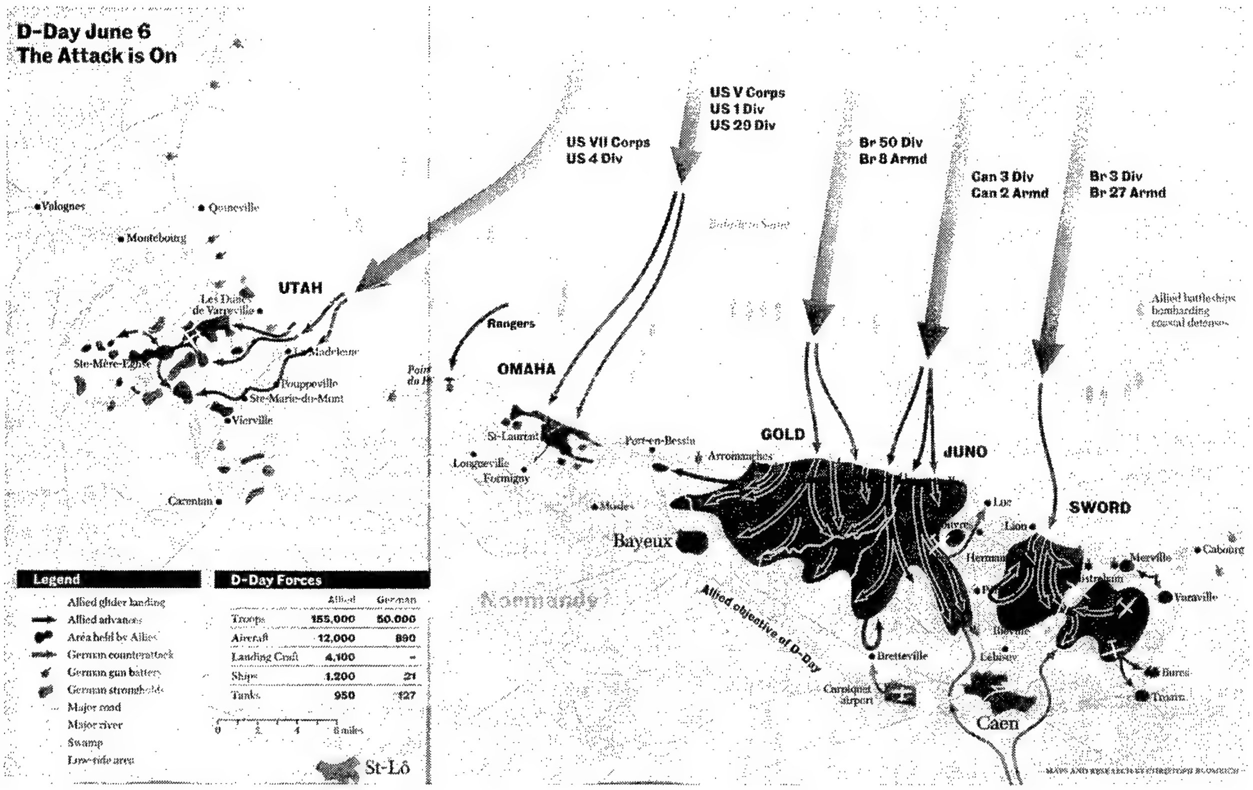


Figure 4. Map of invasion beaches, Normandy, France, 6 June 1944 (from Newsweek 1994)

Figure 5. Aerial photograph of the Mulberry "B" Harbour at Arromanches, Frances, June 1944 (from Institution of Civil Engineers, London, England, 1948, p. 242)

More details of this storm and the damage to the harbor components are given in Appendix B.

The Mulberry Harbor was of two parts. The portion closer to shore, in shallower water, had breakwaters of reinforced-concrete vertical wall caissons (code name "Phoenix") and sunken ships (referred to as "blockships" by the British). These were towed across the English Channel to the site, positioned, and sunk to the bottom. Inside the sheltered region were pierheads and flexible mile-long pontoon-supported flexible bridges (causeways—code name "Whales"). Seaward of these breakwaters were the moored floating breakwaters ("Bombardon," about the shape of a Maltese cross in cross section, each unit 200 ft in length, 25-ft beam, 25-ft hull depth, and 19-ft draft). They were installed in pairs, with a 50-ft gap between contiguous pairs, for a total length of over 2 miles, providing a larger area of sheltered space and deeper water (from 7 to 13 fathoms below mean low water springs, with a 24-ft tide range) for deep-draft ships. The planned layout of the inner harbor is shown in Figure 6, and the layout with construction progress between D+12 and D+44 is shown in Figure 7. Breakwater units destroyed or moved during the gale are indicated.

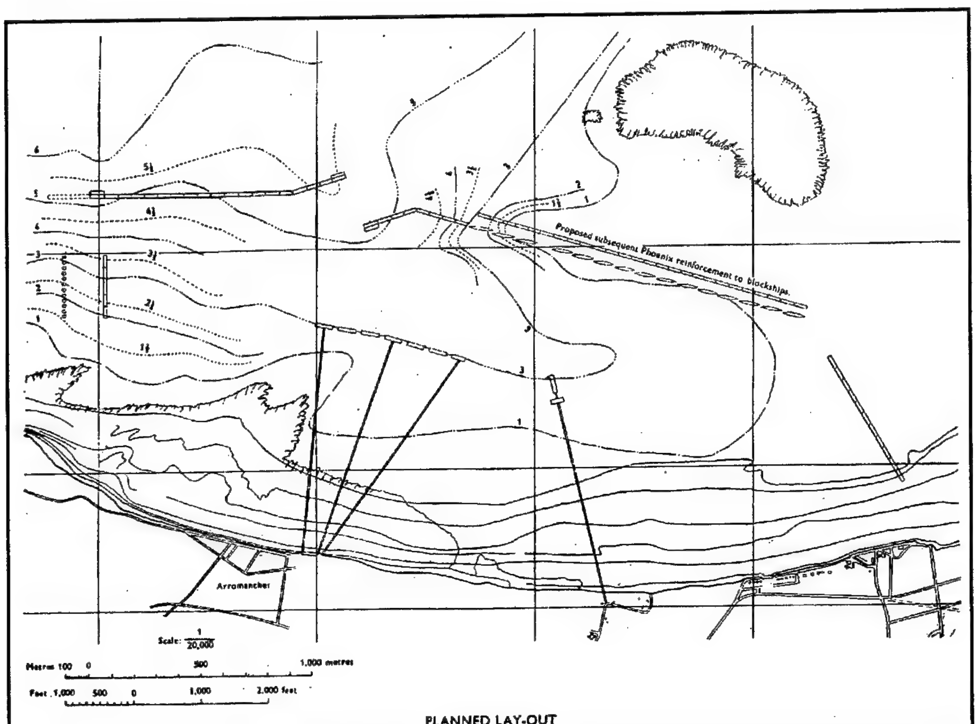


Figure 6. Mulberry "B" Harbour, Arromanches, Normandy, France; planned layout (from Jellett 1948)

There was substantial coastal engineering executed in the design of the two Mulberry harbors ("A" at St. Laurent (Omaha Beach) and "B" at Arromanches): wave and tide prediction (design was for 24-ft tide range), wave diffraction, wave-induced forces, bottom conditions, and placement of structures and their foundations. Details of design, installation, and performance are discussed in *The Civil Engineer in War. A Symposium of Papers on War-Time Engineering Problems. Volume 2, Docks and Harbours* (Institution of Civil Engineers 1948). Wave-diffraction theory to predict wave transmission about a breakwater tip and penetration into the lee of the structure and through breakwater gaps was

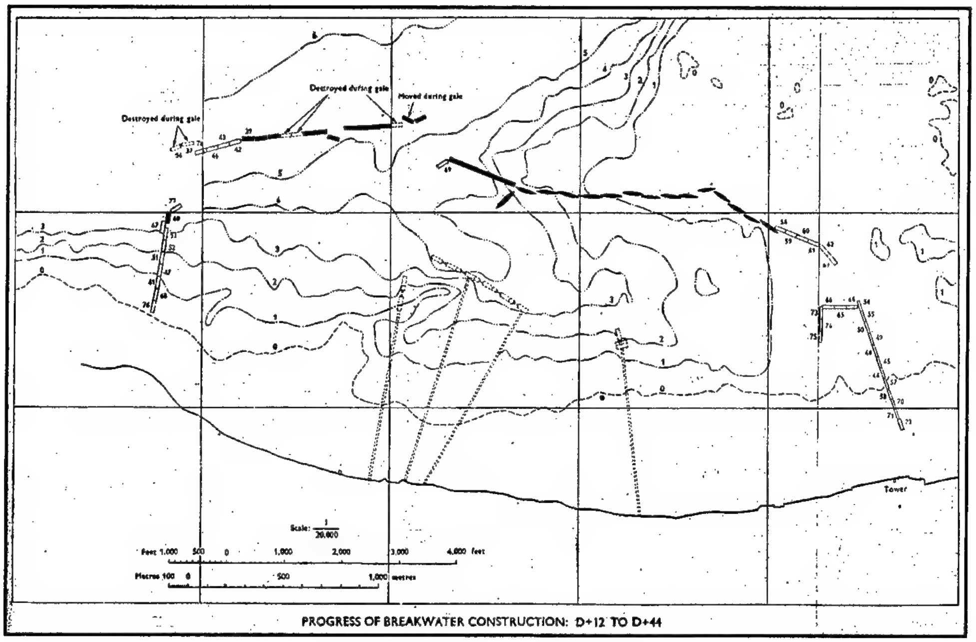


Figure 7. Mulberry "B" Harbour, Arromanches, Normandy, France; progress of breakwater construction, D+12 to D+44 (from Jellett 1948)

developed for this project (Lockner, Faber, and Penney 1948; Penney and Price 1952). (An illustration of wave diffraction at a breakwater is shown in the aerial photograph of Figure 8.) Hydraulic model tests were made in a wave tank in the U.K. to evaluate several mobile breakwater concepts (Todd 1948). Tests were used to obtain data to estimate mooring loads for the floating breakwater. Both functional and structural design was necessary. Todd stated:

> "It was finally decided to adopt a wave-breaker having complete vertical walls without any openings." This "...also greatly simplified the construction work and thereby saved time in building..."

The code name for the vertical-walled breakwater unit was the "Phoenix" unit. Todd noted that there were very few actual measurements of wave forces or pressures on vertical walls at that time. For a short time after WW II, John H. Carr at Caltech, Adel M. Kamel at the U.S. Army Engineer Waterways Experiment Station (WES), and J. J. Leendertse at the Naval Civil Engineering Laboratory made studies on vertical-walled structures; but as most nonmilitary breakwaters in the USA are of the rubble-mound type, there has not been a continuance of these types of studies in the USA.

Many months after the invasion, vast amounts of cargo were still being discharged over the Normandy beaches by DUKWs (2-1/2-ton amphibious trucks called "ducks"), operating from cargo ships in open roadsteads and the shore. The relationship between surf height and daily discharged tonnage at Omaha Beach, October 1 to 28, 1944, is presented in graphical form by Seiwell (1947), Figure 9. According to Seiwell (1947):

Figure 8. Wave diffraction at Channel Islands Harbor, California, detached breakwater (aerial photograph) (from USACE, Shore Protection Planning and Design, 3rd ed., 1966)

"a. Wave heights less than 2 feet in the exposed Channel did not affect the normal discharge of cargo. b. Wave heights of 3 to 5 feet in the exposed Channel caused a reduction of up to 80 per cent in discharged tonnage. c. Wave heights in excess of 7 feet caused all Dukw operation to cease."

Figures 10 and 11 provide an idea of what the littoral zone looks like at low tide for the large tidal range, fine sand, flat-beach region of the invasion coast. Figure 12 (taken in 1988) shows remnants of the Mulberry "B" caissons at

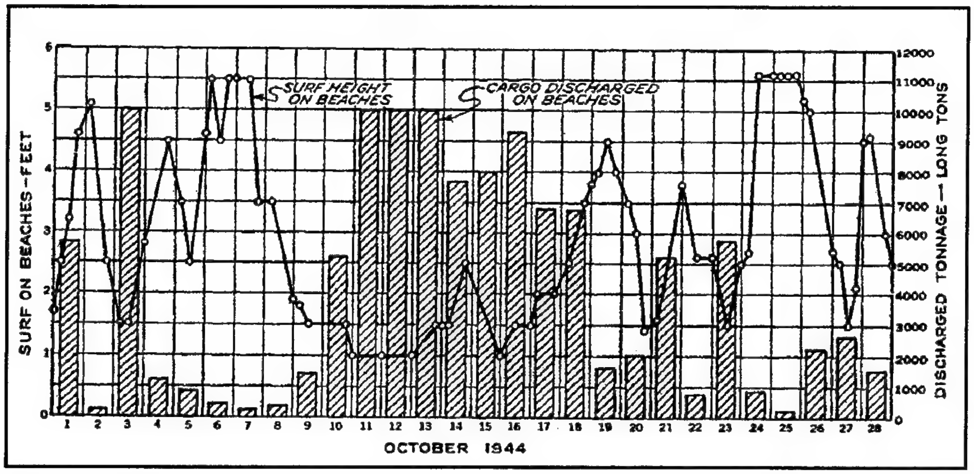


Figure 9. Observed relationships between surf heights and daily discharged tonnage, Omaha Beach, October 1 to 28, 1944 (from Seiwell 1947)

Figure 10. Bars/runnels, low tide, Normandy coast, France, 2 September 1988 (by R. L. Wiegel)

Arromanche, while Figure 13 is the monument at Utah Beach to the 1st Engineer Special Brigade who landed there on H-Hour, D-Day.

It was not just in Normandy that storms caused heavy damage during WW II. For example, during the operation (which started on 15 September 1944) at Peleliu in the Palau Islands, where ragged coral reefs exist, Doane (1945) notes:

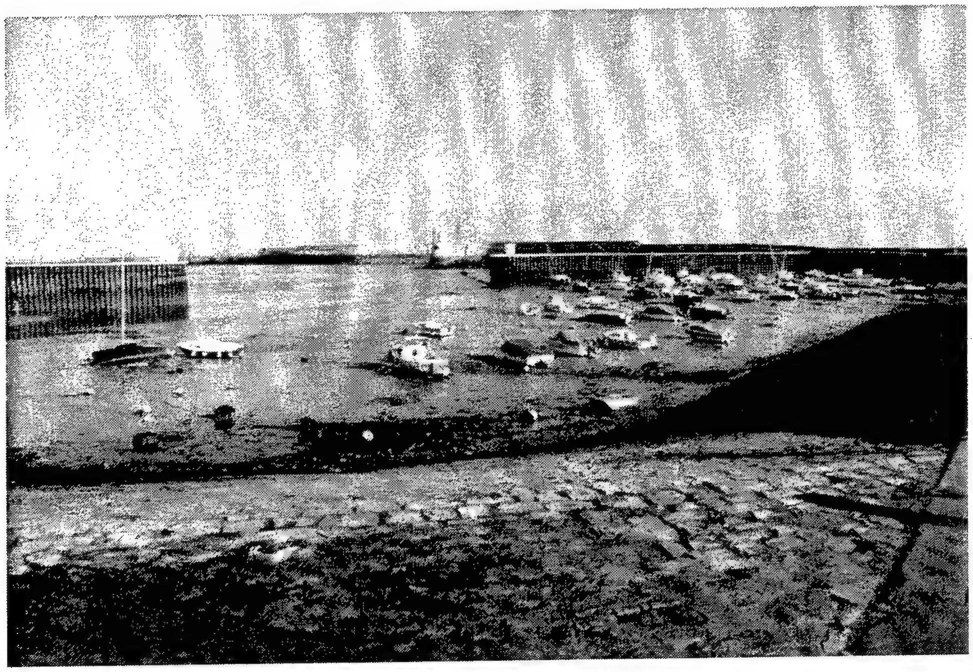


Figure 11. Low tide at Port-en-Bassin, Normandy, France; boats sitting on bottom, 3 September 1988 (by R. L. Wiegel)

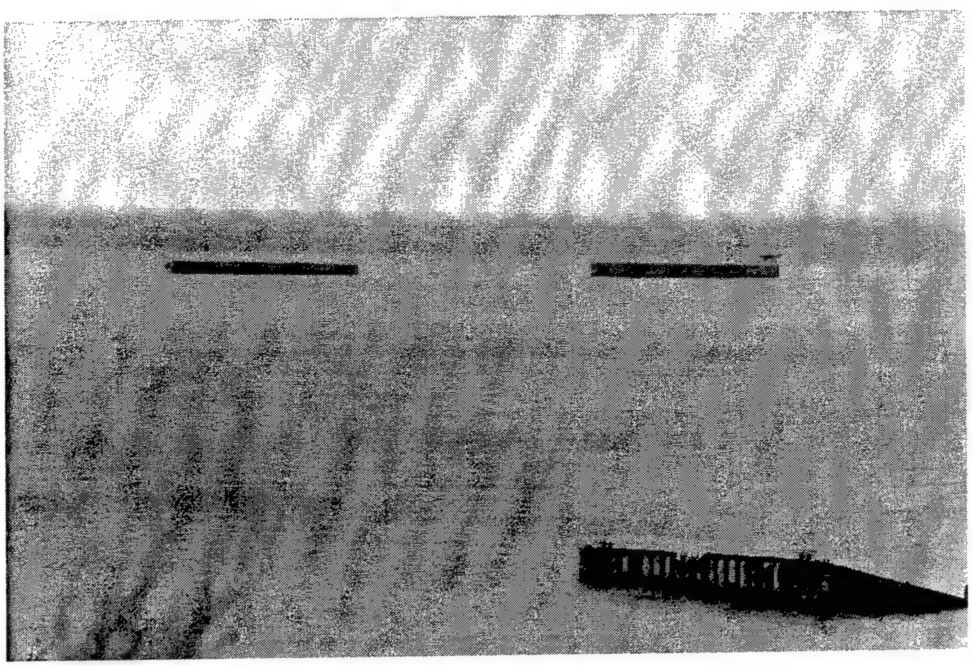


Figure 12. Arromanche, Normandy, France; remnants of Mulberry "B" Harbour, 3 September 1988 (by R. L. Wiegel)

Figure 13. Utah Beach, Normandy, France; monument to 1st Engineer Special Brigade, 3 September 1988 (They landed here at H-Hour, D-Day, 6 June 1944) (by R. L. Wiegel)

"About two weeks after the causeways were installed, a heavy storm broke them apart and scattered them over several miles of the beaches. About 3 weeks later the Seabees started to dredge a channel and small boat harbor with the repaired pontoon causeway forming a bulkhead for the basin. Pontoons were placed along the channel to form a dock, and these were filled with coral to prevent their floating and make a stable dock..." "During the tropical storm of November 6, the pontoons on the east side of the island broached and were broken up, and those on the west side between the unloading dock and the shore were broken apart and spread over a mile of the beach along with dredges and barges. The unloading dock which had been constructed of pontoons filled with coral remained in position through the storm."

A little before the Peleliu operation, there was a major Army assault in the southwest Pacific, of Biak Island, New Guinea, on 27 May 1944. Heavey (July 1945) states:

"The installation of ponton causeways at Biak was the first instance of their use in the Southwest Pacific. As expected they proved very valuable and were slated to be used in many of our subsequent operations. The only difficulty in their use is holding them in place in storms and in cases where lateral currents are strong. Guy lines can hold only so long. Driving pile dolphins seems the best solution but that is difficult to do in the early stages of an operation."

The ponton causeways were launched from a landing ship tank (LST). For more detail see Anonymous (1946, pp. 86-90).

A word of advice on amphibious operations was given by Brigadier General William F. Heavey, Commander of the 2d Engineer Special Brigade during WW II (May 1946):

> "It must be remembered, however, that no two beach operations are ever the same. Tide, surf, enemy opposition, and obstacles vary in every case so that accurate comparisons of any two operations are impracticable."

3 Post-World War II Military Coastal Engineering Studies

As a part of the work on amphibious operations/oceanography done at the University of California, Berkeley (UCB), during 1946-1952 for the Marine Corps under contract with Office of Naval Research (ONR), the author read the operations reports for most of the Marine Corps assaults in the Pacific. Many landing craft and amphibian-vehicle casualties were due to enemy action, but more were caused by problems associated with waves and currents (i.e., capsizing, swamping, broaching, getting stuck on bars, and filling with water and sand when the ramps were down (Isely and Crowl 1951, p. 517). Port Lyautey, Morocco, on the Atlantic Ocean (9 November 1943) is one example of a military operation in which waves caused most of the damage to landing craft:

> "In the morning sun all spirits rose. So did the breakers. Soon we could land no more supplies or tanks on the beach because of the high surf. Already scores of our landing craft were broached on the beach" (Henney 1944).

Another example was the Army landing at Nassau Bay, New Guinea (Heavey 1944; also, see Anonymous 1946, pp. 39-40):

> "...due to the storm, the leading wave of LCVP's hit the beach only to encounter 10 to 12-foot surf, but no [enemy] ... It was too much for our boats. Only a few were able to retract before being swamped by the high surf...Twenty-one of our LCVP's were left turned every which way on the beach and pounded into distorted shapes by the heavy seas."

Another major problem needing research to come out of WW II amphibious experience was beach trafficability. Vehicles were continuously getting stuck in the beach sand. The volcanic cinder sand on the steep beach at Iwo Jima (Morris 1948) was particularly difficult for vehicles to maneuver on. Trafficability tests were made on some USA beaches as a part of the UCB Institute of Engineering Research (IER) project (Wiegel 1950). A study was made of trafficability and its relationship to sand characteristics, beach slope, water level, and vehicle type for the U.S. Naval Civil Engineering and Evaluation Laboratory (Horonjeff et al. 1953). One observation cited from the earlier UCB IER studies was "...the saturated sand near the water's edge was caused to liquify due to the vibrations produced by vehicular traffic. As a result the vehicles would sink and become stuck." Some examples of trafficability problems are shown in Figure 14 (DUKW stuck in a hole made by a landing craft vehicle personnel (LCVP); 2-1/2 ton 6x6

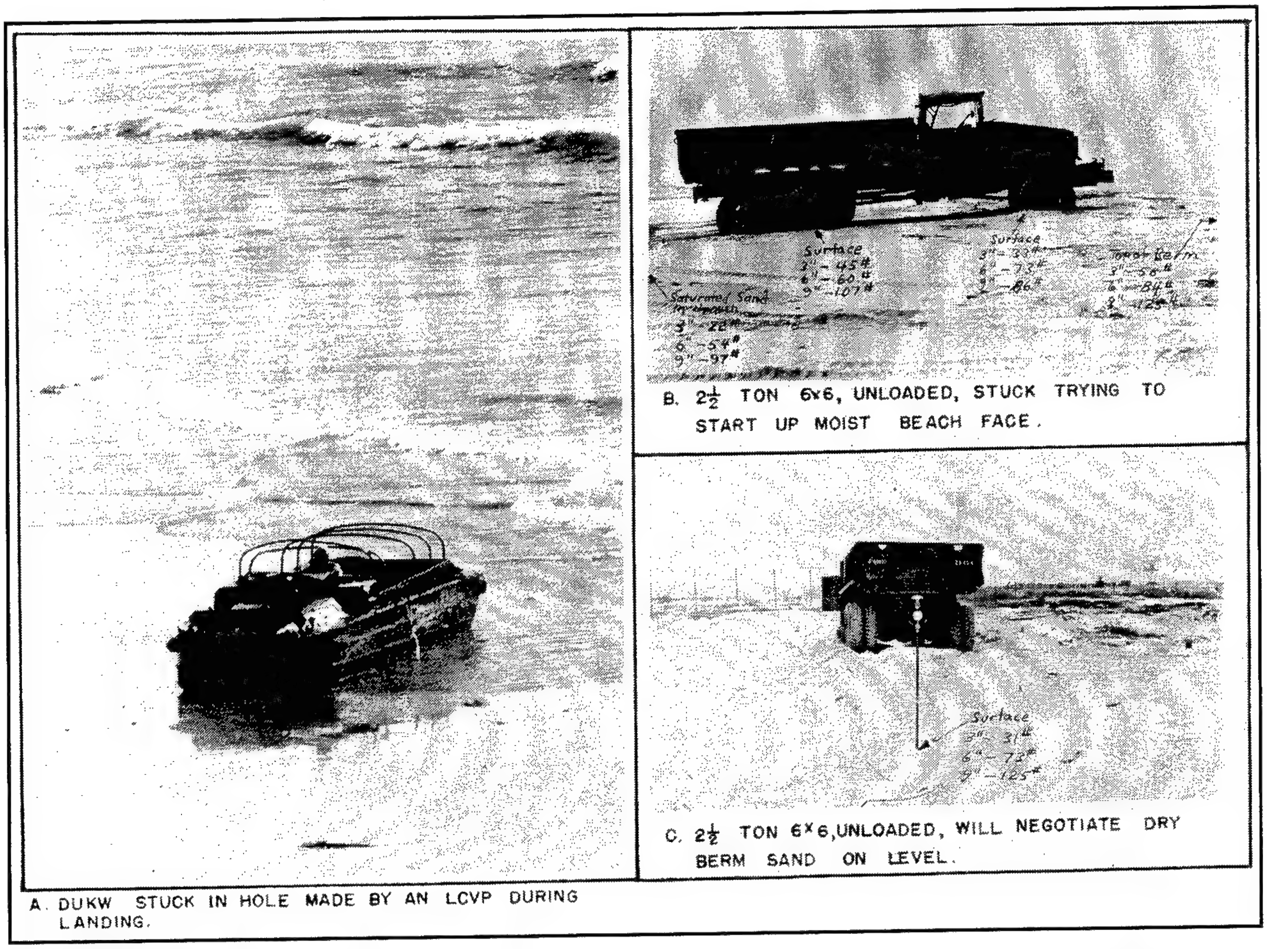


Figure 14. Beach trafficability scenes, DUKW and 2-1/2 ton 6x6 truck, Santa Margarita River Beach, Camp Pendleton, CA, 1949 (from Wiegel 1950)

truck stuck on moist beach face ("liquefaction"), a cone penetrometer used for estimating soil strength) and Figure 15 (amphibian tractor in trouble on a small scarp, 2 ft high, which had been cut by waves the day before). Photomicrographs of beach sand grains, Figure 16, show variability in size, shape, and texture. For scale, the small vertical marks along the top are 1/64 in. apart. Trafficability depends on these characteristics and on the water content of the beach.

An extensive field study of many of the nonenemy-inflicted problems of amphibious operations was a part of the work by UCB IER. Field observations were made at locations where the beaches/surf were very different: Camp Pendleton, CA; Monterey Bay, CA (Fort Ord/Del Monte); Clatsop Spit, OR (on the south side of the mouth of the Columbia River); Waianae, Oahu, HI. A major part of the studies was to learn about amphibian-vehicle performance in high surf, judged to be unsafe for personnel. Owing to this, a remote control system was developed and used with a landing vehicle tank (LVT) for some tests. Many technical reports were written, and they were summarized in *Summary Report of Amphibious Studies for the Period 1 January 1949 to 31 December 1950* (Wiegel et al. 1951). As an example, the joint effect of wave steepness and beach slope on breaker type was found to be very important to landing craft/amphibian-vehicle performance (Patrick and Wiegel 1955). The ratio of these two values (now

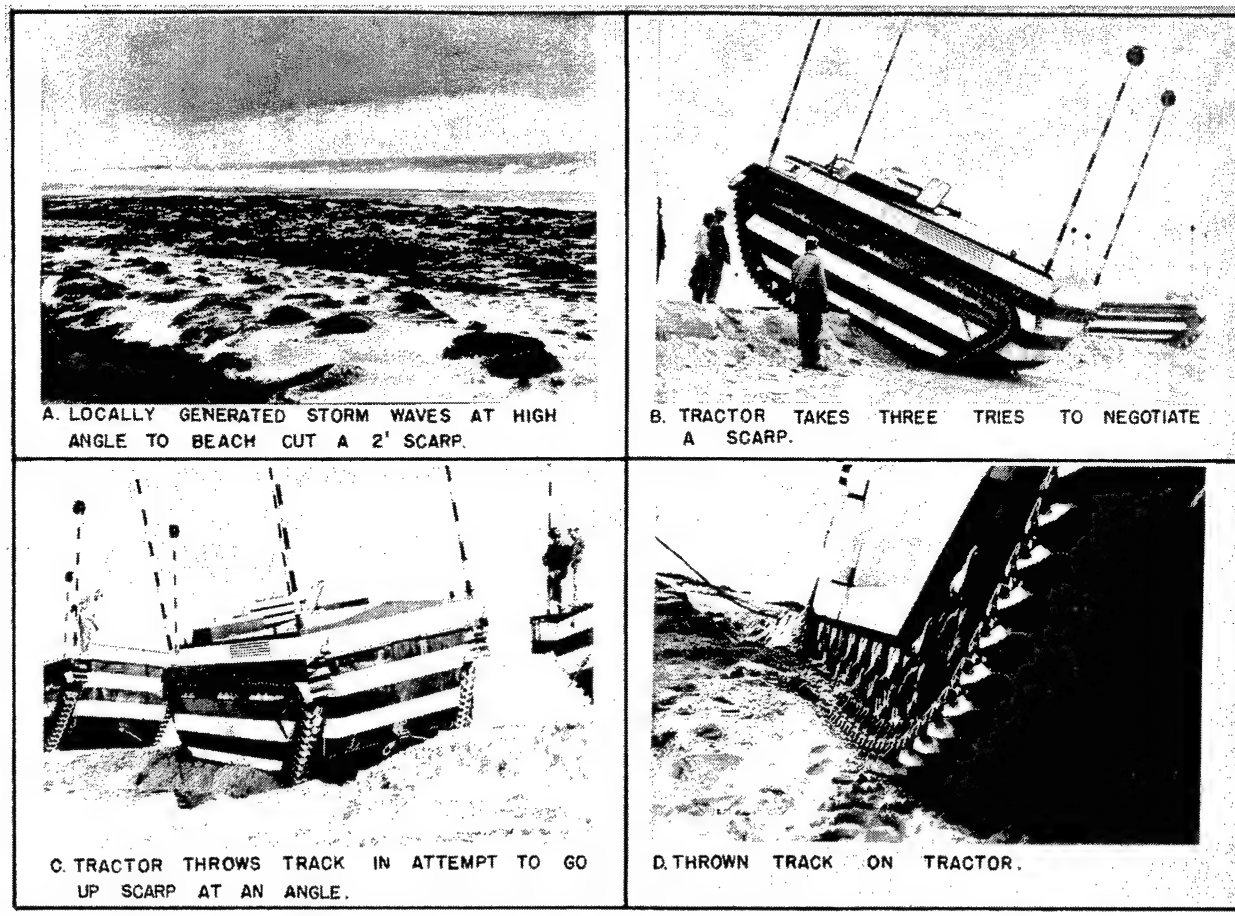


Figure 15. Formation of a small scarp and trafficability effect on an LVT, Santa Margarita River Beach, Camp Pendleton, CA, 1949 (from Wiegel et al. 1950)

known as the Irabarren Number or "surf similarity parameter") was later found by Hunt (1959) to correlate well with wave runup on sloping breakwaters, and much later found by others to predict the type of wave breaking on beaches. Many others were involved in making observations and developing theories useful for explaining some of the nearshore littoral zone phenomena; for example, surf beat (e.g., Munk 1949).

Detailed observations were made of several full-scale amphibious assault-training exercises, and reports were written on the observations and findings. One was Operation MIKI, across three west coast beaches in the Waianae—Pokai Bay region of Oahu, Hawaii, on 25 October 1949 (Wiegel and Kimberley 1949). On two of the beaches, there were substantial landing-craft casualties on the shore face due to wave action, owing to the combination of long-period waves and steep beach face, with waves surging up the beach face. (There was a similar situation on Iwo Jima - Thompson (1996-1997, p.38).)

Four photographs (Figures 17-20) are given of beach landings. The first, Figure 17, is of a training exercise at the Marine Corps' Camp Pendleton, California, on 25-26 November 1946 (beach of medium steepness, about 1/35; wave period about 11 sec, characteristic breaker height about 3-1/3 ft, maximum

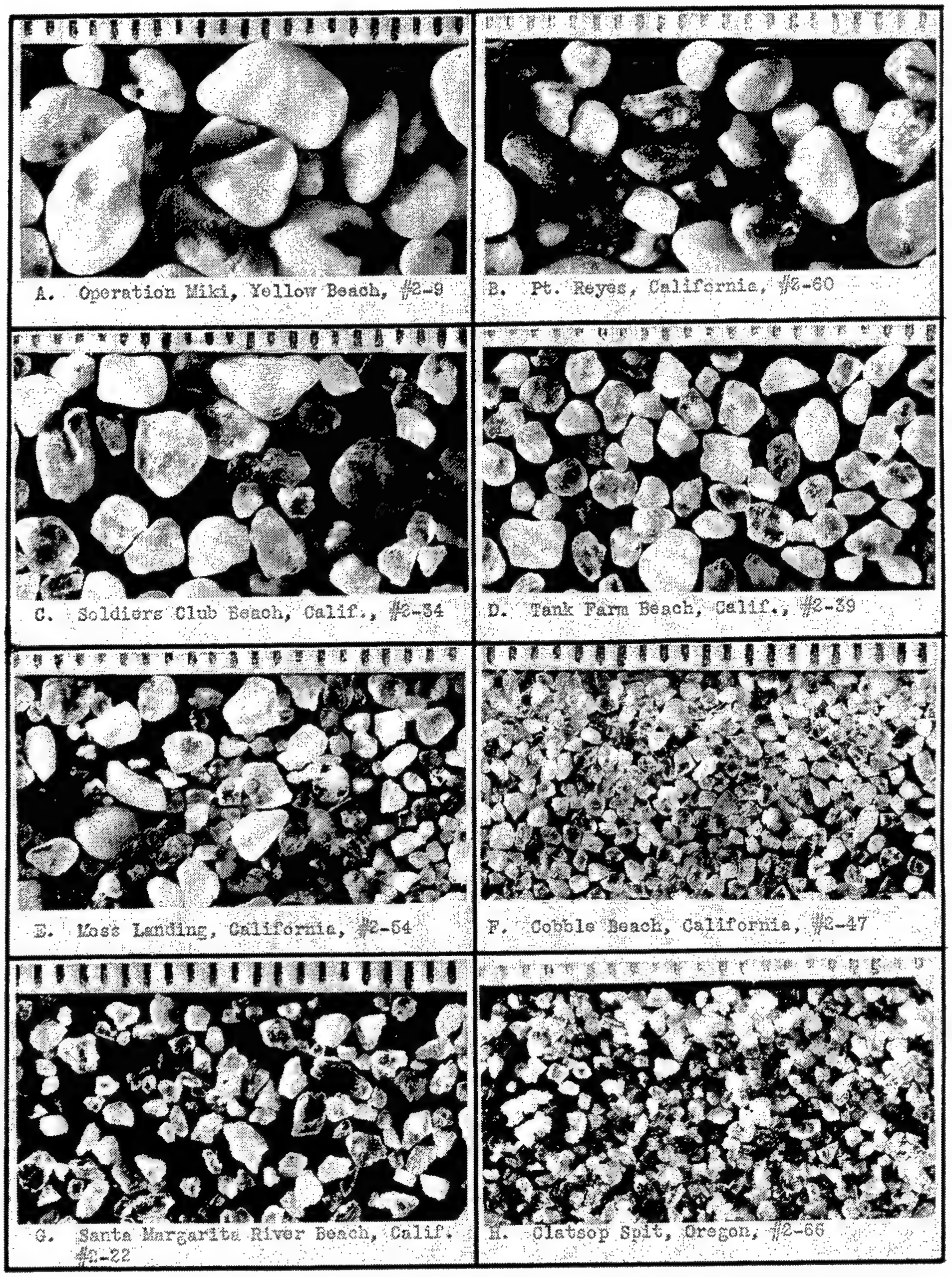


Figure 16. Comparison of photomicrographs of sand samples arranged from steepest beach to flattest beach studied (scale, 1/64 in. between vertical marks) (from Wiegel 1951)

about 4-1/2 ft, breaker angle about 15 deg from the west, alongshore current about 3/4 knot southeasterly). Figures 18-20 are of the Operation MIKI training exercise over three adjacent steep-pocket beaches, about a mile apart, at Waianae, Oahu, HI, in October 1949. Figure 18 shows a congested beach ("Green Beach" in Pokai Bay, steep beach face, with low waves—significant wave height about 2 ft). Part of the congestion is due to the fact that the operation at one of the other beaches had to be canceled, as described below. Two of the beaches ("Yellow" and "Blue") had a steep beach face, but were gently sloping in the nearshore.

Figure 17. Amphibious assault training exercise, Camp Pendleton, CA, 25 November 1946; landing ships and landing craft in the surf and on the beach (from Foight, Bascom, and Isaacs 1947)

Long swell resulted in surging breakers on these beaches. "Yellow Beach," about a mile to the east of "Green Beach," had a steep face of about a 1 on 5 slope, but the waves were higher than at "Green Beach" (from 4 to 6 ft). Figure 19 shows an LCM being struck by a surging breaker. This craft never made it to the beach, but had to return to sea. There were many landing craft casualties on this beach.

Figure 20 shows many LCVPs broached and shoved onto the steep beach by surging breakers on "Blue Beach," about a mile west of "Green Beach," beach face slope about 1 on 5, and significant wave height of 5 to 6 ft, wave period 16 to 17 sec. The author was an observer at this beach and recorded that 20 LCVPs landed in three "waves" in the first 15 min of the amphibious operation; 7 retracted; and 8 were destroyed. Some had filled with water and sand when the ramps were down. Operations over this beach were then halted. Five of the craft were salvaged later. This type of surf was named "surging breaker" (see Patrick and Wiegel 1955) for waves that surged up the beach face, often without breaking. The beach face was sufficiently steep such that the waves reflected back to sea rather than broke.

Major theoretical advances in the physics of wave generation by wind in deep water were made during the post-WW II period (in the 1950s) by Owen Phillips

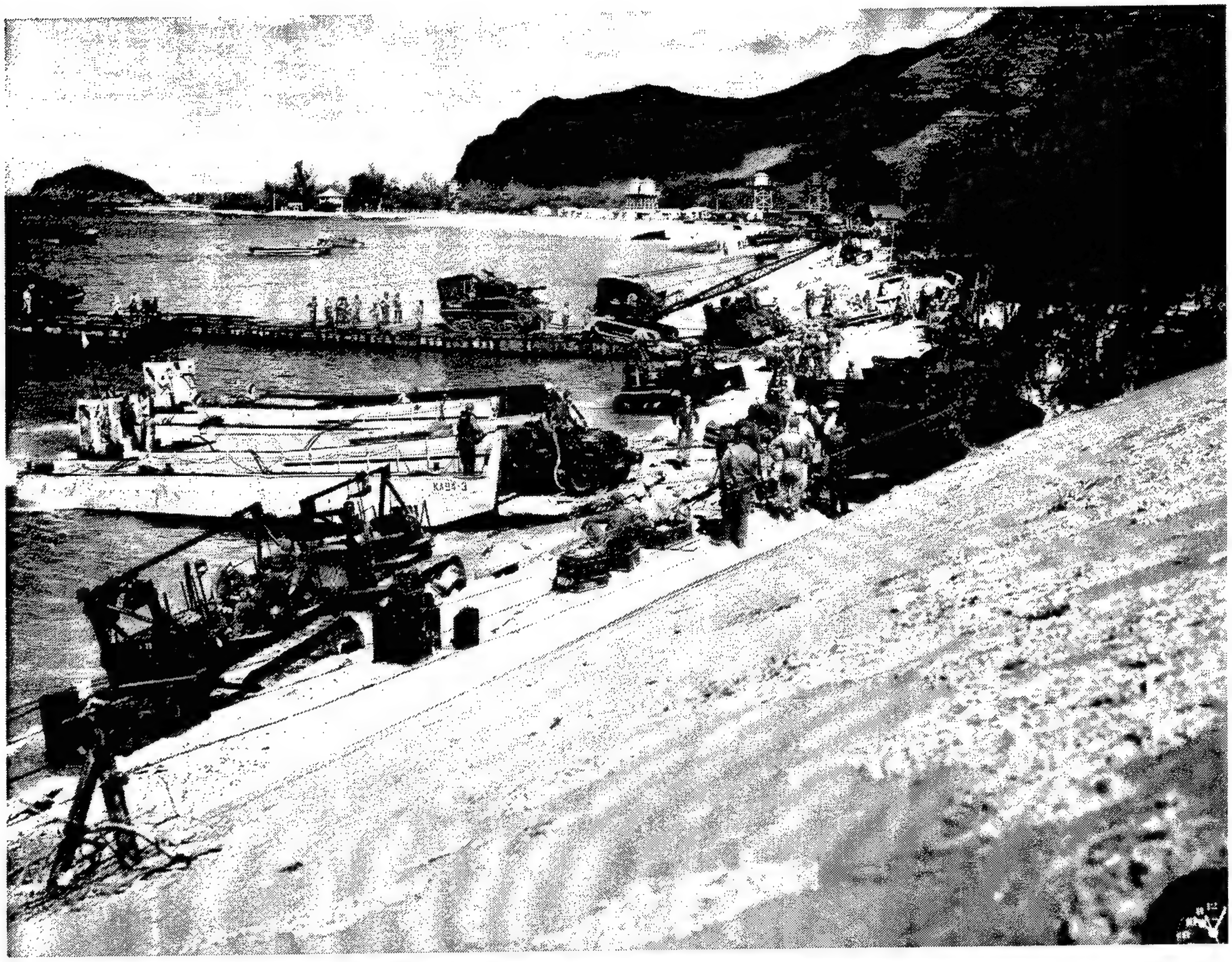


Figure 18. Operation MIKI, Waianae, Oahu, HI; congested beach during amphibious assault training exercise, October 1949 (from Wiegel and Kimberley 1949)

and by John Miles. The spectral approach of Pierson, Neumann, and James and that of Moskowitz were developed during the postwar years.

Development of helicopters and air cushion vehicles was started after the end of WW II because of the problems of moving personnel, equipment, and supplies through the surf and over the beach. For information on air cushion landing craft, see Dukes (1984).

Some beach and surf characteristics that are important in coastal engineering (military and civil applications) are shown in Figures 21-25. Figure 21 shows beach cusps, and Figure 22 is of long-crested waves breaking at an angle with the beach, generating alongshore currents that move sand, craft, and people. Littoral currents are not always as simple as might be thought from the aerial photograph of Figure 22. Figure 23 shows rip currents and beach cusps on a steep beach, at Fort Ord, Monterey Bay, CA. For scale, note the DUKWs on the beach. Rip currents occur at many locations and cause drownings. They can be used to advantage by DUKWs that are leaving the beach via riding the "rip" seaward. Rip currents come and go at most locations, but are semipermanent at others.

Figure 19. LCM being struck by surging breaker on steep beach face (craft returned to sea without making landing), Operation MIKI, Waianae, Oahu, HI, October 1949 (from Wiegel and Kimberly 1949)

Figure 24 shows seasonal cut and fill of beach profile changes along the pier at the Scripps Institution of Oceanography, La Jolla, CA. Consider what the effects of these changes might be on surf-zone minefields, obstacles, and pipelines. Figure 25 shows the relationships among sand size, beach slope, and exposure to waves.

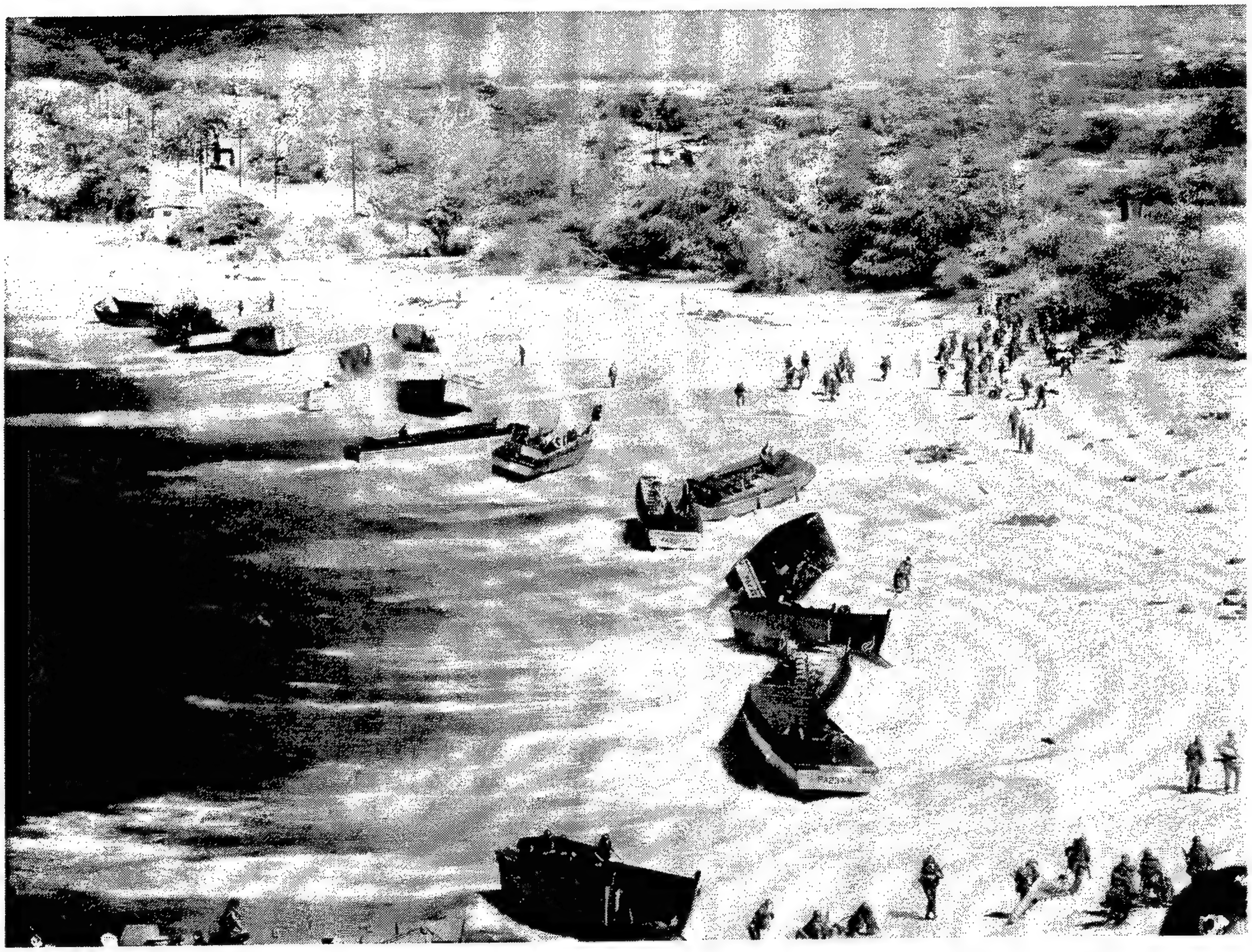


Figure 20. Many LCVPs broached and shoved onto the steep beach by surging breakers; Operation MIKI, Waianae, Oahu, HI, October 1949 (from Wiegel and Kimberly 1949)

Figure 21. Beach cusps, El Segundo, Santa Monica Bay, CA (by U.S. Marine Corps, probably 1949) (from Wiegel et al. 1951)

Figure 22. Long-crested waves breaking at an angle with beach; alongshore currents generated (by U.S. Marine Corps 1949)

Figure 23. Rip currents and beach cusps on a steep beach, Fort Ord, Monterey Bay, CA, 1 March 1950 (for scale, note DUKWs on beach) (by U.S. Marine Corps) (from Wiegel et al. 1950)

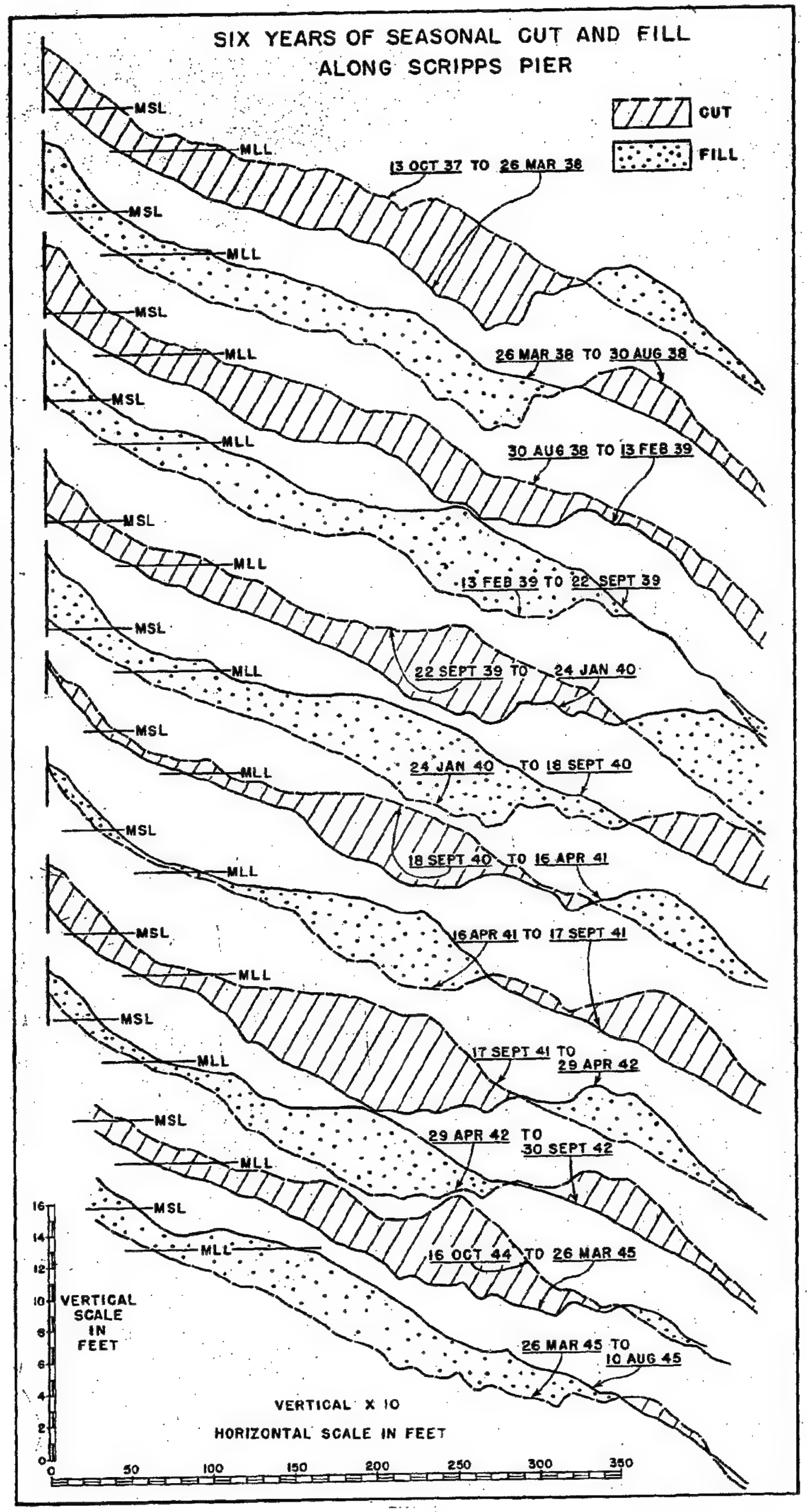


Figure 24. Beach profile surveys along pier at Scripps Institution of Oceanography, La Jolla, CA, for 6 years; seasonal cut and fill (from Shepard 1950)

(From: OCEANOGRAPHICAL ENGINEERING by Robert L. Wiegel, Prentice-Hall, Inc. 1964, 532 pp)

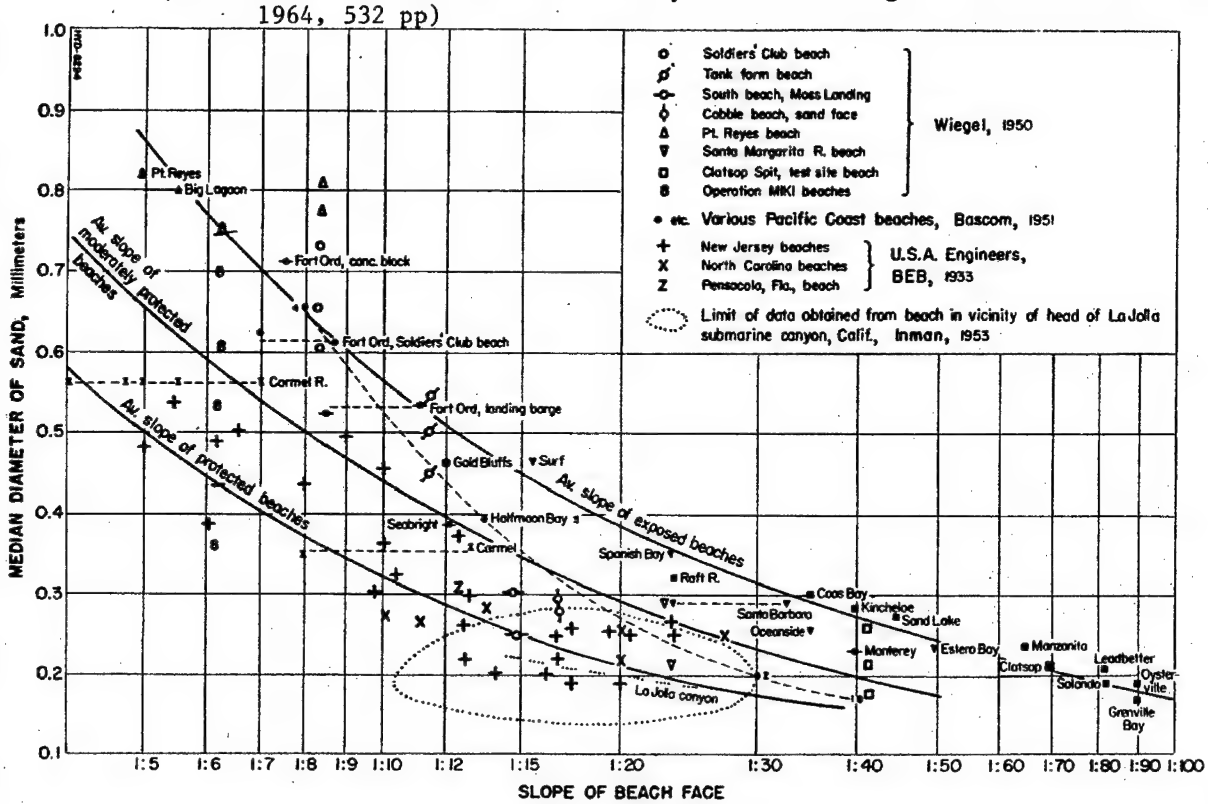


Figure 25. Size-slope-exposure relationship of beaches at the reference point (from Wiegel 1964)

4 Amphibious Operations, Republic of Korea (ROK)—Mud and Tides

"The south and west coasts of the Republic of Korea have extensive mud flats and hundreds of small conical islands, while the east coast is mostly rocky seacliffs and pocket beaches of sand. At Inchon, "...tidal flat deposits maintain substantial exposure at least 50 km offshore at low tide" (Wells and Huh 1979).

The tides at Inchon have a large range, with an extreme range from approximately -2 ft at low tide to +32 ft at high tide. McCollam (1952) notes:

"At the extreme low tides mud flats are bared for miles out from shore, and the only approach to the port is through a narrow channel at present little over 3 to 6 feet deep at zero tide and correspondingly less at minus tides."

An amphibious assault was made at Inchon, Republic of Korea; D-day was 15 September 1950. A 1950 chart (from Japanese surveys dating to 1937) of the region is shown in Figure 26. According to Lovell (1952):

"General MacArthur said ... conception of the Inchon landing would have been impossible without the assurance of success afforded by the use of the Seabee pontoon causeways and piers."

Mann (1952) noted that:

"Manmade structures in approximately 60 percent of the area surrounding the beach and port area had been destroyed. And worse than that was the 30-foot tide which exists at the harbor. It was the first time many of the engineers had seen a sea of water change so quickly to a sea of mud or vice versa. Getting onto the beaches required meticulous timing and a slight delay might mean being ignominiously stranded in the mud."

Experiments were made at UCB IER and the Navy Civil Engineering Laboratory prior to the landings on stabilizing mud and sand with additives. The attempts at stabilization were not successful for operational purposes.

The Inchon port had a tidal basin and facilities; these were relatively intact at the time of the invasion. The lock gates were demolished during the U.S.

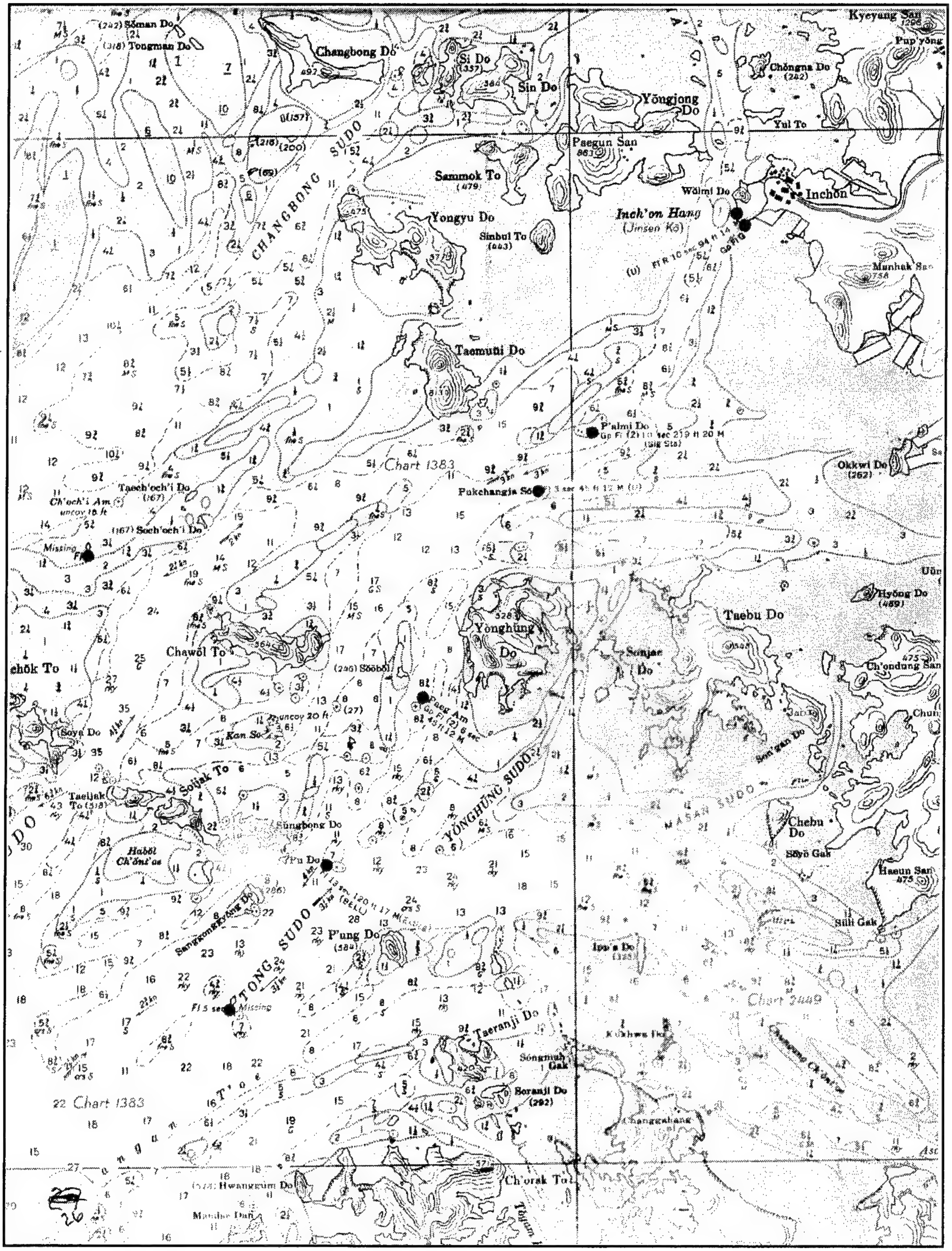


Figure 26. Inchon area; part of U.S. Navy Hydrographic Chart No. 3237, May 1950; datum, Indian Spring Low Water; from Japanese surveys to 1937 (from U.S. Navy Hydrographic Office 1950)

evacuation in January 1951 and were rebuilt by the 50th Engineer Port Construction Company upon the return of U.S. forces in February 1951 (Mann 1952; McCollam 1952). The location of the tidal basin and lock gates can be seen in Figure 27.

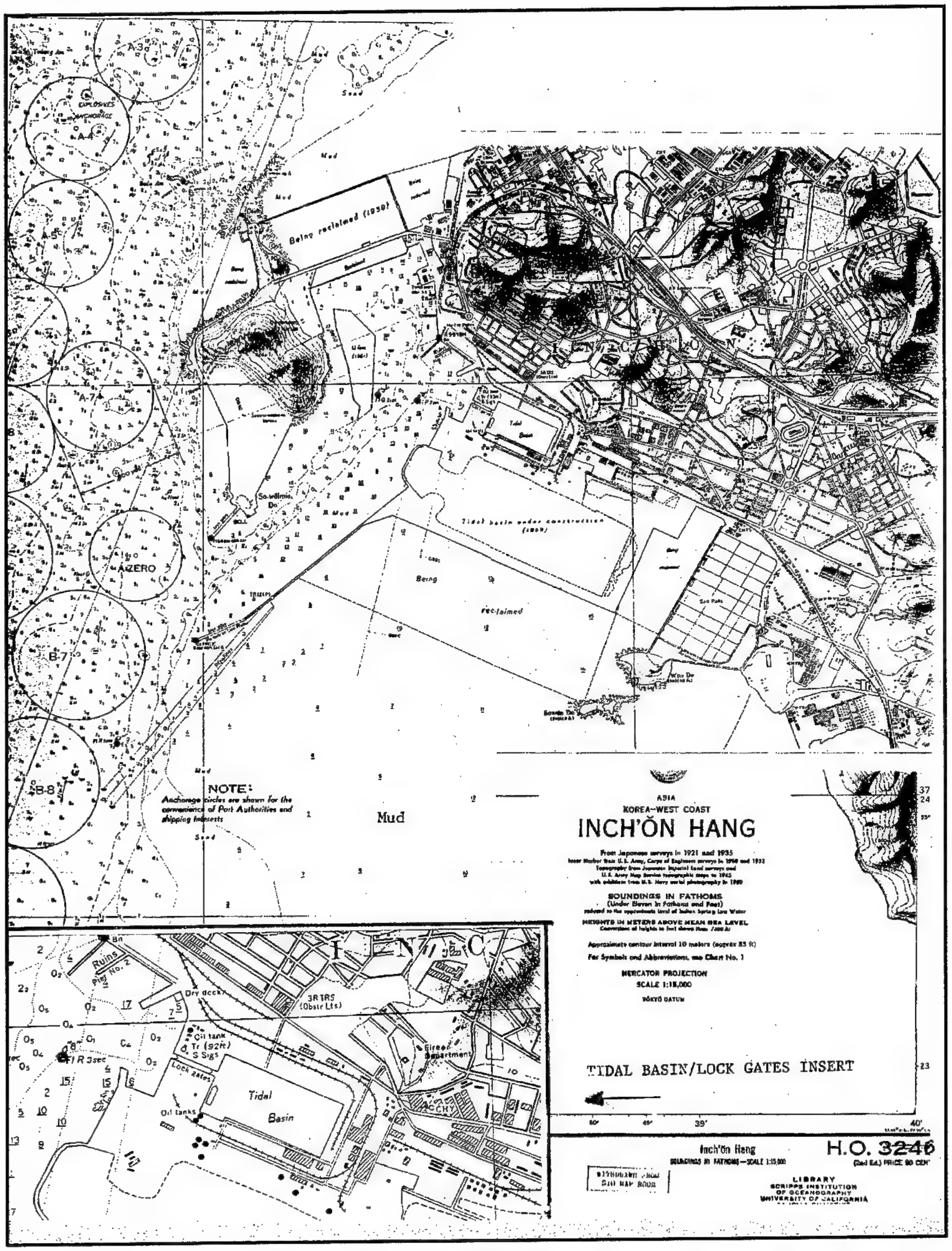


Figure 27. Incho'on Hang; part of U.S. Navy Hydrographic Office Chart 3246, from Japanese surveys in 1921 and 1935, and inner harbor from U.S. Army Corps of Engineers surveys in 1950 and 1952 (Note location of tidal basin and gates) (from U.S. Navy Hydrographic Office 1952)

5 Vietnam, Port Operations

Peter F. Lagasse (1979) describes the coastal engineering studies by the U.S. Army Corps of Engineers (18th Engineer Brigade) from mid-1966 to mid-1967 for port facilities in Vietnam, including ramps for landing craft and LSTs.

The U.S. Navy OICC (Officer in Charge of Construction) was responsible for deep-water ports at Saigon-Newport and DaNang. Studies were made for dredging planning for these sites and seven other sites, with data collected on coastal sediments, storms, tides, and waves (Daniel, Mann, Johnson & Mendenhall, DMJM, 1966). Wave data collected were also in a report by A.H. Glenn & Associates (1966), a subcontractor to Brown and Root, Inc. According to Lagasse:

> "The Army port construction program included four berths at Qui Nhon, two berths at Vung Ro, ten berths at Cam Ranh, and two berths at Vung Tau, as well as numerous shallow-draft and lighterage facilities.... Detailed port facilities design was accomplished in-house by the port construction section using baseline data from the earlier OICC studies (References 1-5) and relying heavily on the U.S. Army Coastal Engineering Research Center's Technical Report No. 4, *Shore Protection Planning and Design,* (11), as a source of data and techniques currently used in the solution of coastal engineering problems."

Earlier work was documented by Yens and Clement (1966, 1967).

Successful port facility operation was in part due to the DeLong Corporation's installation of piers and prefabricated causeway components and their use of self-elevating work barges. For information on uses of mobile self-elevating platforms, floating breakwaters, and portable reflecting wave barriers, see DeLong Corporation(1959).

The sand on many of the Vietnamese beaches was such that "... with heavy use becomes almost impassable, severely limiting over-the-shore lighterage operations" (Lagasse 1979). In an earlier report (Yens and Clement 1966), attempts of stabilizing the sand were described (rock, concrete articulators, pierced-steel planking, and others), with a beneficial life range from a matter of days to 2 weeks. Also, waves over the foreshore undermined the stabilizing structures, and the bearing capacity decreased, resulting in the structures virtually sinking out of site. Engineers learned of WW II and subsequent experience with coral for stabilizing beaches (e.g., Bemont 1951) and used underwater deposits of coral in stabilization measures. Blasting and draglines were used for excavation

of the coral. The coral was crushed and then moved to the landing sites. Yens and Clement (1967) state:

> "The foreshore area was excavated to 18 inches and crushed coral was then placed in layers and compacted with rollers, and then the beach was graded to its original alignment. This process gave very satisfactory results and lasted several months with only minor repairs."

The work described by Lagasse (1979) included the installation of the "expeditionary port at Vung Ro to support the major tactical air base at Tuy Hoa," Figure 28. Typhoon and prevailing (monsoon) waves were estimated, and wave refraction studies were made for this port, Figure 29. These studies were used in planning the port layout, Figure 30, which:

> "...included LST ramps, a floating pontoon cube barge dock, and a two A barge DeLong pier (600 x 80-feet) with two girder spans off a 120 meter rock fill causeway...Port development also included the installation of tanker mooring facilities and submarine pipeline west of the main port area, and a six inch pipeline running 9.6 kilometers to a...tank farm south of the Tuy Hoa airstrip." "...seven months after completion these structures survived a typhoon which produced wave conditions exceeding the design wave criteria."

Two photographs of the port facilities are shown in Figure 31.

Tuy Hoa (pronounced "twee-whah"), about 240 miles north of Saigon on the South China Sea, was developed into a major jet fighter (F-100s) base in 1966-1967. There were no port facilities nearby, and equipment and supplies were delivered across the beach with amphibious invasion-assault methods (using LCMs (landing craft mechanized), LCUs (landing craft utility), and LARCs (lighter, amphibious resupply cargo)). According to Curtin (1977):

> "... with cargo from deep-draft ocean vessels being lightered in barges and landing craft onto the beach adjacent to the construction site. During the monsoons and high seas, the unloading operations were moved 22 miles south to the protected waters of Vung Ro Bay. Then the landing craft and barges made their way up the coast to the mouth of the Da Rang River, where an entry channel and turning basin were dredged into a sheltered area behind the sand spit."

Tuy Hoa is used as an example, as the author was a consultant at a late stage in the project, after much dredging had been done. It was an Air Force project still under construction when the author visited the operation on 18 and 19 November 1966 (Wiegel 1966). The coastal area south of Tuy Hoa and north of Vung Ro was still contested, with a tactical operation planned by the Army to secure it. The U.S. Air Force wanted the harbor constructed. They were doing it on their own with a "turnkey project," not an Army or a Navy project. There is a great amount of sand in this region, brought to the coast by rivers. The USACE had made recommendations (e.g., Woodbury 1966), based on studies by J. M. Caldwell, R. Y. Hudson, and others of the Coastal Engineering Research Center

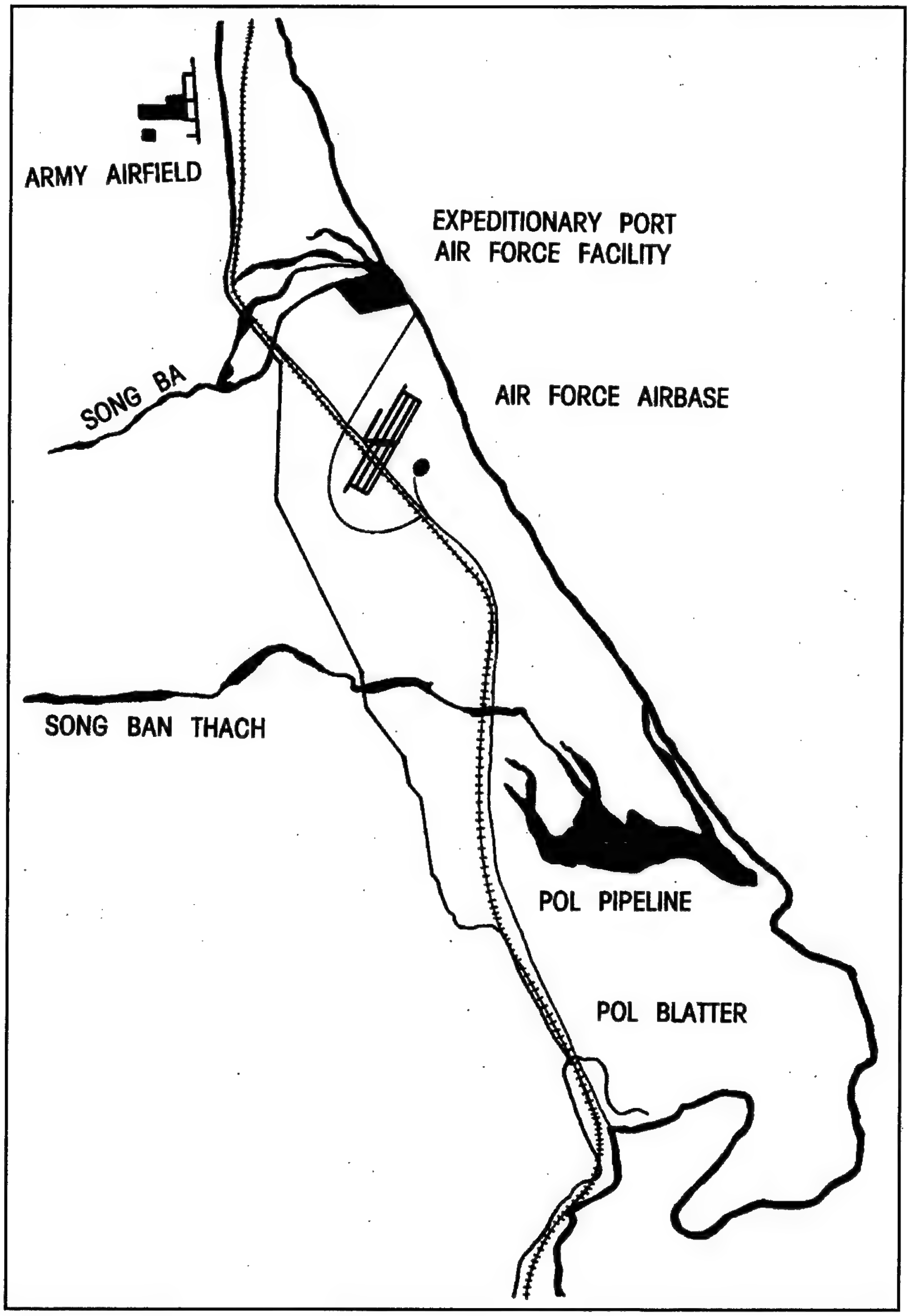


Figure 28. Sketch map of Vung Ro to Tuy Hoa, Vietnam (from Lagasse 1979)

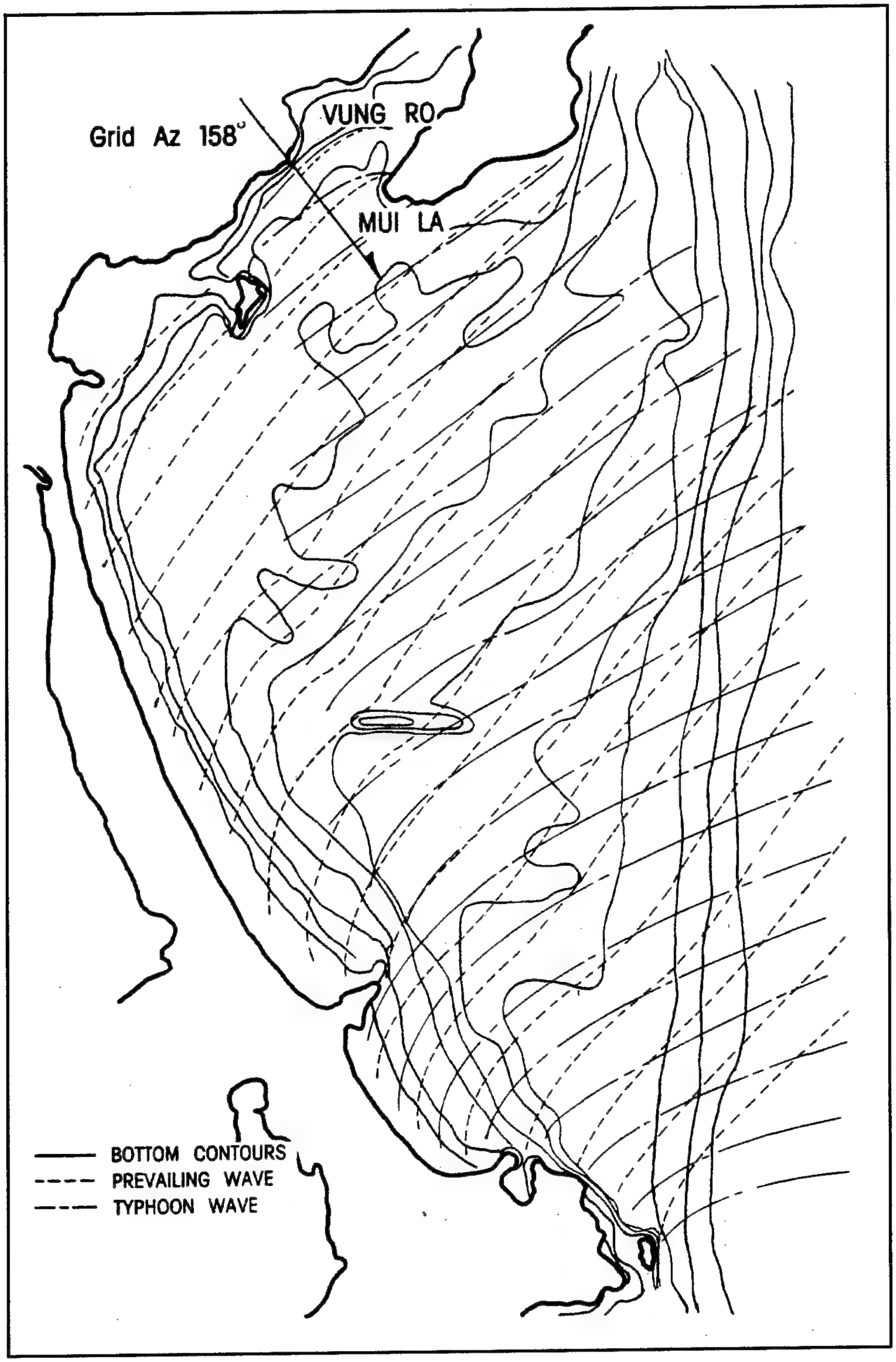


Figure 29. Wave refraction study, Vung Ro port, Vietnam (from Lagasse 1979)

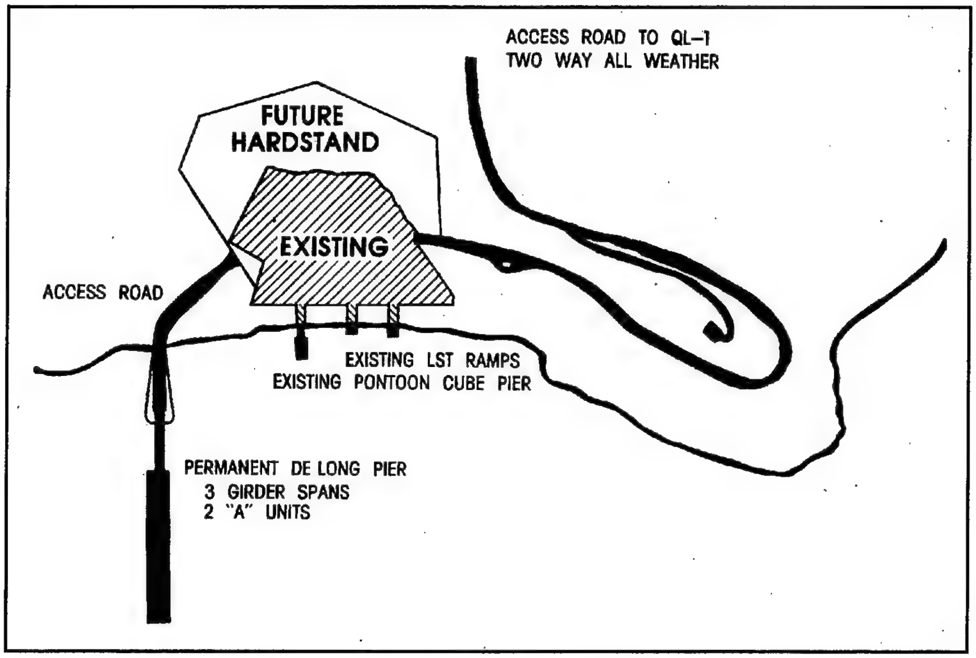
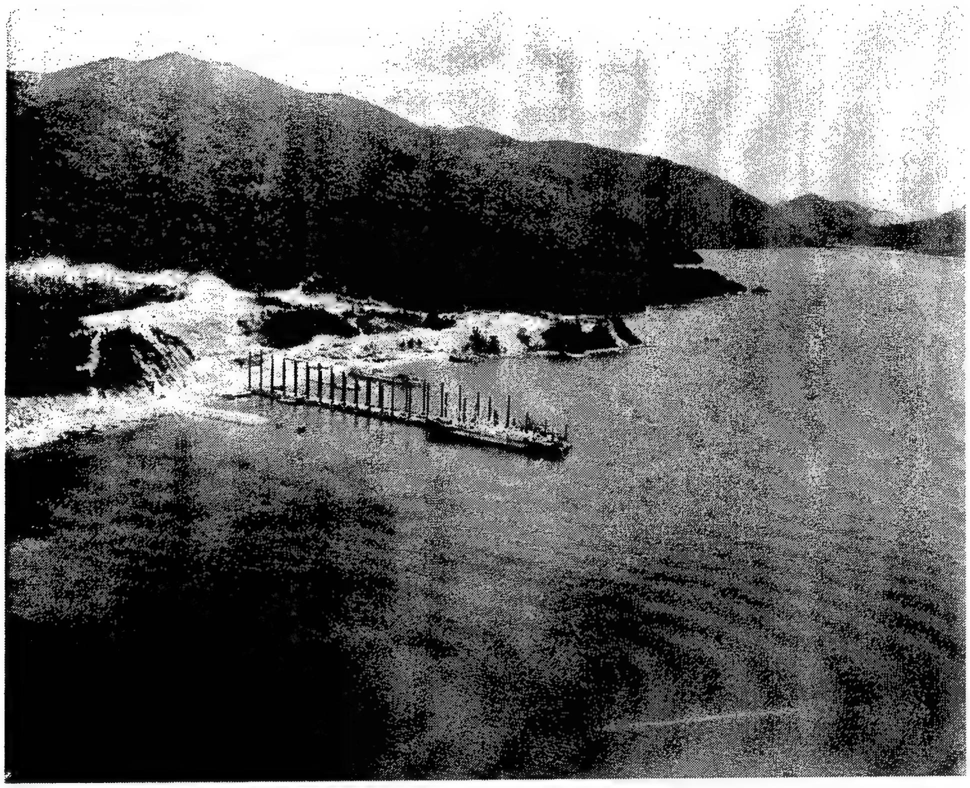


Figure 30. Vung Ro, Vietnam, port layout (from Lagasse 1979)

and WES. The site recommended by the USACE studies was several miles south; it also required jetties and dredging of the entrance, but the 3-fathom line was much closer to shore than in the immediate vicinity of the river mouth. A hydraulic model study of the entrance and jetties was done at WES for the U.S. Navy (Wilson 1966). However, the Air Force was having the port constructed at the mouth of the Da Nang River, Figure 32.

The dredging of the harbor was nearly complete when the author was there, and a partial channel had been dredged through the bay mouth sandbar just south of the natural inlet at the mouth of the Song Da Rang (Da Rang River), Figures 33, 34, and 35; note in Figure 34 the ship aground on the beach, and in Figure 35, waves breaking on the ebb-tide bar. One question the author was asked was about the possible use of sunken ships as entrance jetties rather than rubble mound, owing to the long time required to construct rubble-mound jetties. The author recommended against it, owing in part to what had happened to the "sunken ship breakwater" at Omaha Beach in Normandy during WW II and the likelihood of there being typhoon- or monsoon-generated waves at the site in the future. The recommendation was accepted. The author also recommended that after jetties had been built, the main gap between the north and west islands (which consisted of dredged material) be filled so the river would no longer flow through the harbor. The author called their attention to a general observation of J. H. Douma (1955, p. 5) about tidal entrances where there is much sand:

> "A channel that remains open during normal conditions may be virtually filled during a single severe storm or freshet with suspended of bed-load material carried by the high velocities."



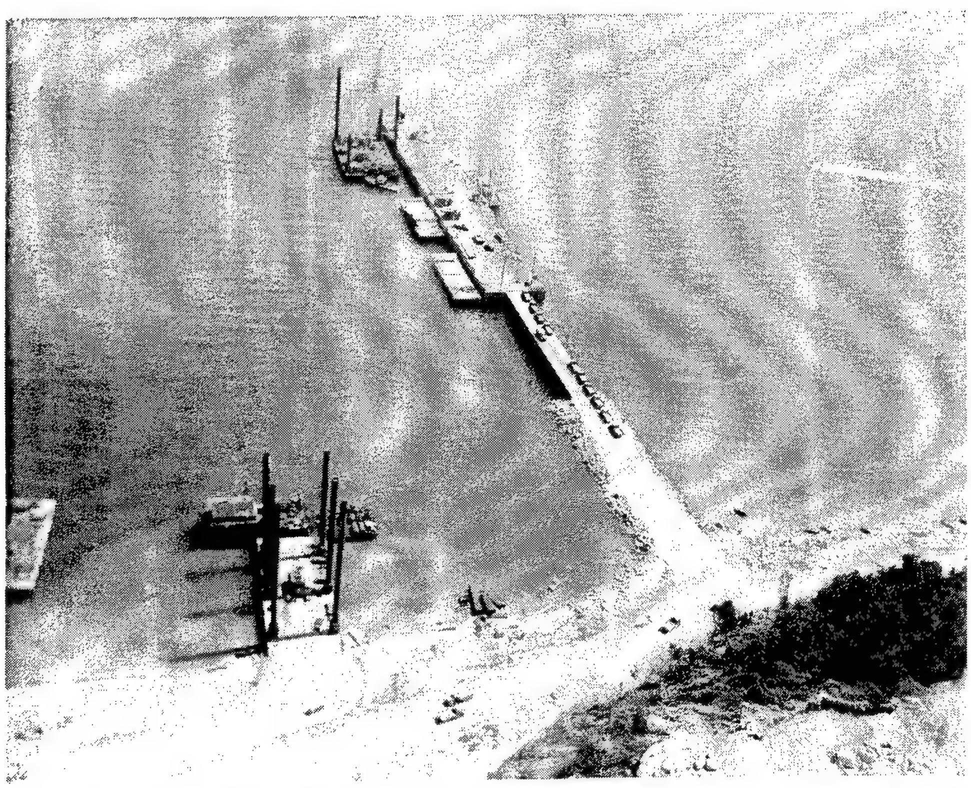


Figure 31. Vung Ro port, Vietnam; aerial photographs, March 1967 (upper) and April 1967 (lower) (from Lagasse 1979)

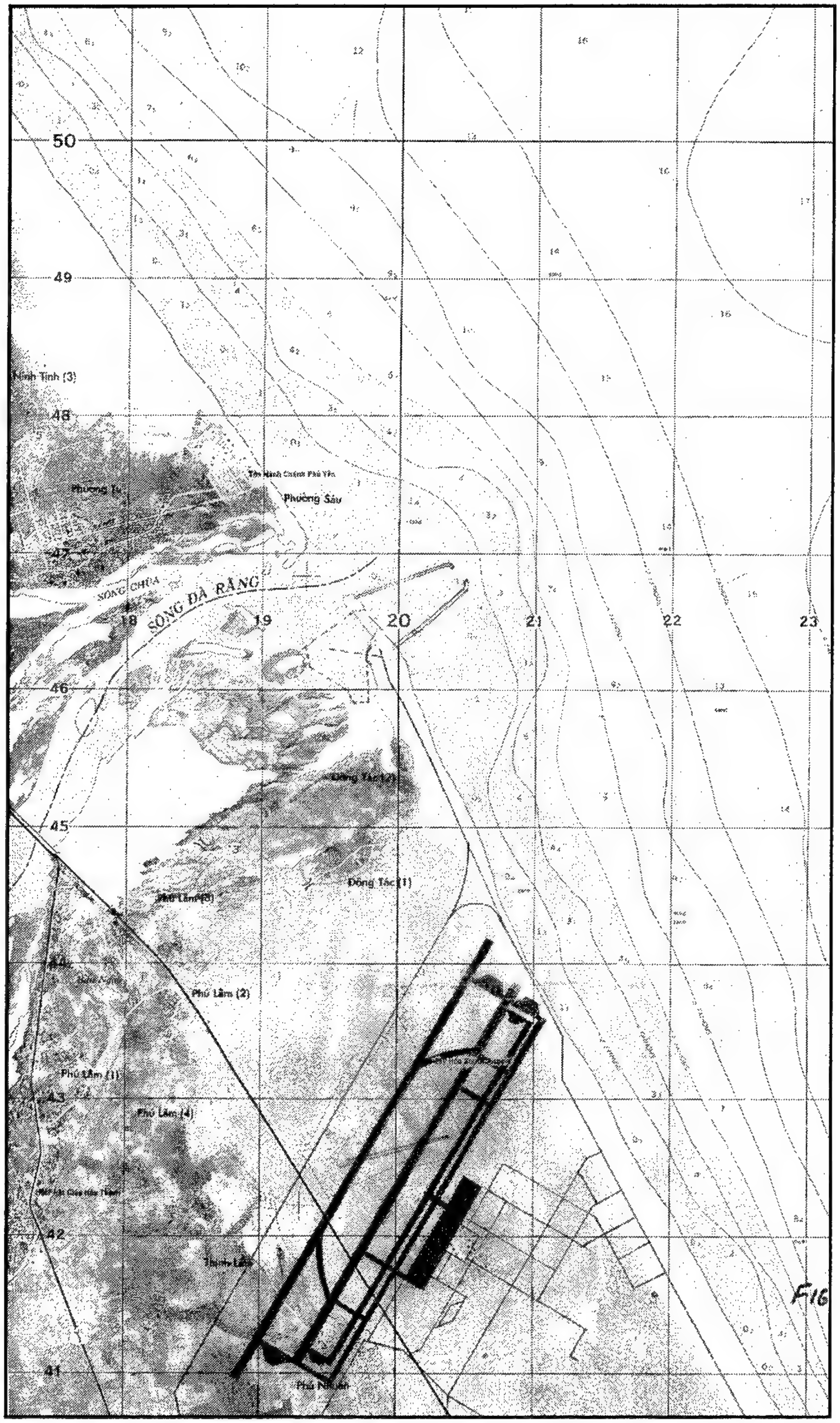


Figure 32. Tuy Hoa, Vietnam; nearshore bathymetry and proposed location of Air Force air base harbor in Song Da Rang mouth (Section of Pictomap Supplement, Vietnam, Sheet 6835 II S (Series L8020); information as of 1965. Depths in fathoms; datum, mean sea level at Ha Tien. From USACE Army Map Service)

Figure 33. Tuy Hoa, Vietnam; aerial photograph of Air Force air base harbor, dredging and entrance (by R. L. Wiegel, November 1966)

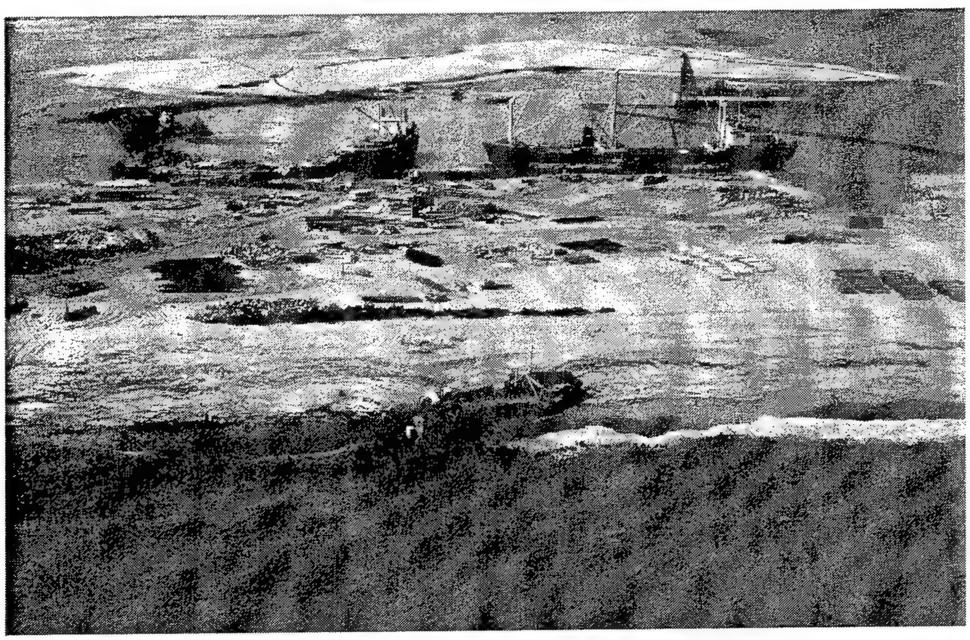


Figure 34. Tuy Hoa, Vietnam; aerial photograph of dredging harbor in Song Da Rang Bay (Note ship aground on beach and ships in harbor. By R. L. Wiegel, November 1966)

"After several months of pilot channel dredging it was conceded by the contractor that installation of a facility (i.e., harbor/port - RLW) at this location was clearly impractical." The harbor project was abandoned (Lagasse 1979).

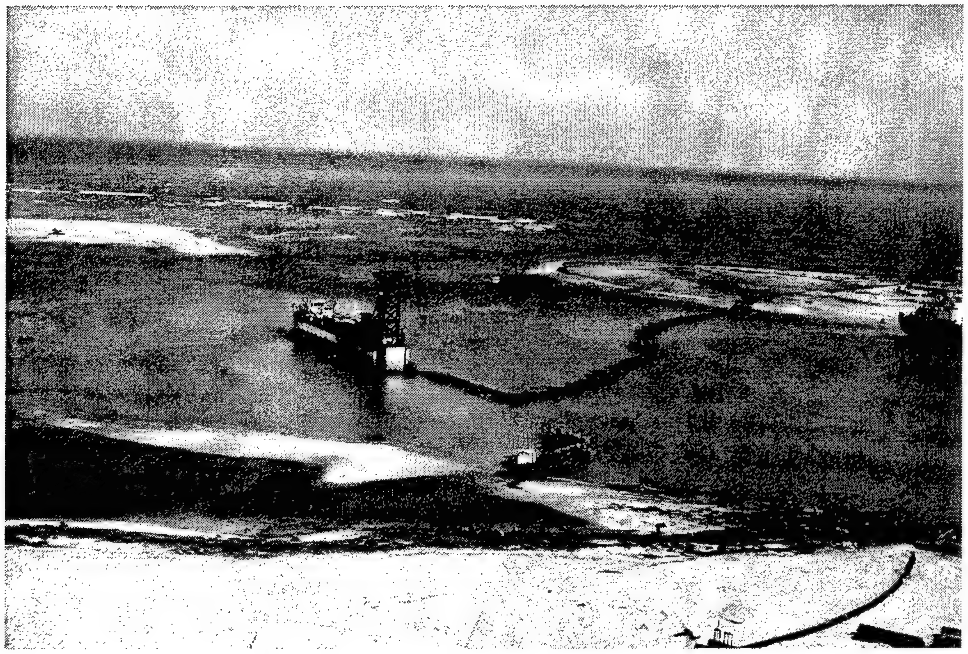
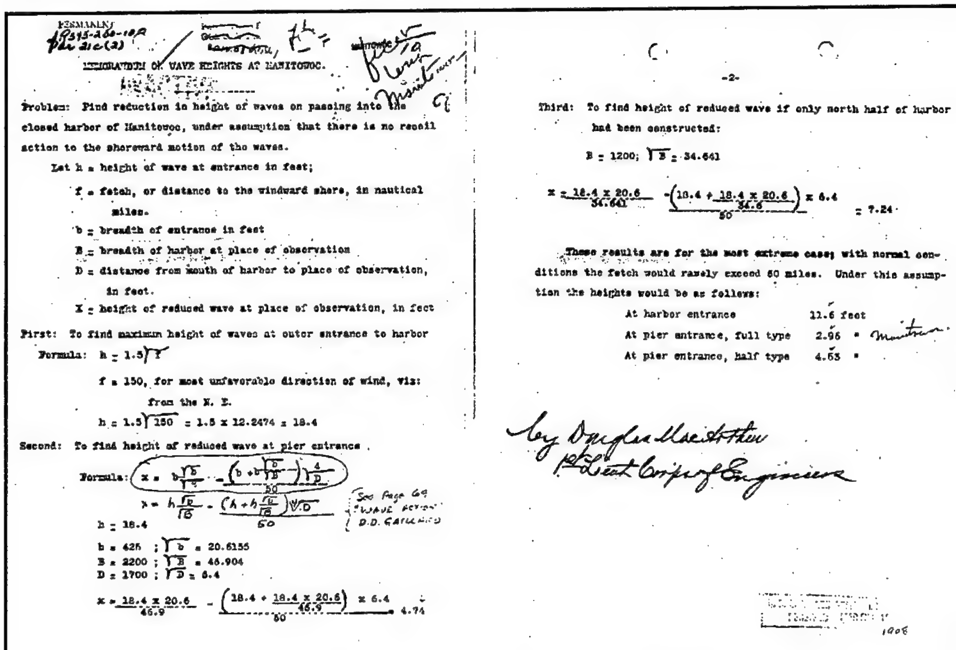


Figure 35. Tuy Hoa, Vietnam; aerial photograph of dredging harbor in Song Da Rang Bay (Note new entrance and waves breaking on ebb-tide bar. By R. L. Wiegel, November 1966)

6 Closure

In closing it is interesting to note that, historically, coastal engineering has been used by at least one senior Army commander with experience in harbor engineering when he was a young Corps of Engineers officer. In Figure 36 are the calculations made of waves at Manitowoc Harbor on Lake Michigan, Wisconsin, by a 1st Lieutenant (Douglas MacArthur), Corps of Engineers (using the formulae given in Gaillard's 1904 book). The calculations are dated March 23, 1908.



MEMORANDUM ON WAVE HEIGHTS AT MANITOWOC.

Problem: Find reduction in height of waves on passing into the closed harbor of Manitowoc, under assumption that there is no recoil action to the shoreward motion of the waves.

Let h = height of wave at entrance in feet;

f = fetch, or distance to the windward shore, in nautical miles.

b = breadth of entrance in feet

B = breadth of harbor at place of observation

D = distance from mouth of harbor to place of observation, in feet.

X = height of reduced wave at place of observation, in feet

First: To find maximum height of waves at outer entrance to harbor

Formula: $h = 1.5\sqrt{f}$

f = 150, for most unfavorable direction of wind, viz: from the N. E.

$h = 1.5\sqrt{150} = 1.5 \times 12.2474 = 18.4$

Second: To find height of reduced wave at pier entrance.

Formula: $x = h\frac{\sqrt{b}}{\sqrt{B}} - \frac{\left(h + h\frac{\sqrt{b}}{\sqrt{B}}\right)\sqrt[4]{D}}{50}$

$x = h\frac{\sqrt{b}}{\sqrt{B}} - \frac{\left(h + h\frac{\sqrt{b}}{\sqrt{B}}\right)\sqrt[4]{D}}{50}$ See Page 69 "Wave Action" D.D. Gaillard

$h = 18.4$

$b = 425$; $\sqrt{b} = 20.6155$

$B = 2200$; $\sqrt{B} = 46.904$

$D = 1700$; $\sqrt[4]{D} = 6.4$

$x = \frac{18.4 \times 20.6}{46.9} - \frac{\left(18.4 + \frac{18.4 \times 20.6}{46.9}\right) \times 6.4}{50} = 4.74$

-2-

Third: To find height of reduced wave if only north half of harbor had been constructed:

$B = 1200$; $\sqrt{B} = 34.641$

$x = \frac{18.4 \times 20.6}{34.641} - \frac{\left(18.4 + \frac{18.4 \times 20.6}{34.6}\right) \times 6.4}{50} = 7.24$

These results are for the most extreme case; with normal conditions the fetch would rarely exceed 60 miles. Under this assumption the heights would be as follows:

At harbor entrance	11.6 feet
At pier entrance, full type	2.96 "
At pier entrance, half type	4.63 "

by Douglas MacArthur
1st Lieut Corps of Engineers

This Memorandum on Wave Heights of Manitowoc, Wisconsin, dated March 23, 1908, by Douglas MacArthur, 1st. Lieut., Corps of Engineers, is in the files of the North Central Division, Corps of Engineers, U.S. Army, Chicago, Illinois.

Figure 36. Memorandum on wave heights at Manitowoc (on Lake Michigan, Wisconsin) by Douglas MacArthur, 1st Lieutenant, Corps of Engineers, March 23, 1908 (from USACE, North Central Division)

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Appendix A
Military Intelligence Information Required (National Research Council, Committee on Amphibious Operations 1951)[1]

"(a) Hydrography, with special emphasis on surf and swell conditions, tides, currents, depths of water, water temperature, and salinity.

(b) Weather with relation to temperature, rainfall, force and direction of wind, frequency of storms, visibility, flying conditions, special phenomena, astronomical data, daylight and dark tables, and sunrise and moonrise tables.

(c) Beaches, with reference to their location, length, width, physical consistency, navigational landmarks, offshore approaches, gradient, nature of bottom reefs, rock shoals, and other possible hazards.

(d) Terrain, especially that immediately adjacent to and behind the landing beaches, with reference to approaches, observation posts, fields of fire, obstacles, cover and concealment, and roads from portions of shoreline on which landings seem practicable to logical objectives inland.

(e) Enemy defenses, .."

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[1] This reference is listed in the References at the end of the main text.

Appendix B
Normandy, Mulberry Harbors, World War II, Storm of 19-22 June 1944

Manning (1944)[1] states:

"At this time, the artificial harbor was approximately 85 per cent completed, and each unit of the artificial harbor (that is, pierheads, bridging, causeways and Rhino's) were actually operating satisfactory....The fury of the storm was sufficient either to sink or tear loose from their mooring all the cruciform units ("Bombardon floating breakwater") in the outer floating breakwater, setting many of them adrift and adding still more to existing hazards... Several units of the reinforced concrete caisson breakwater which were topped by the waves, succumbed to the incessant battering and collisions with floating objects and craft, and were damaged to the extent that some were destroyed almost to low-water and consequently rendered ineffective as a breakwater..." "...the sunken ship breakwater, likewise, was damaged. Practically all vessels, including the British battleship, broke their backs....The damage to the artificial harbor installation at the British beach several miles to the eastward (Mulberry "B") of the American beaches, while serious was not as extensive as the damage to the American harbor (Mulberry "A").... Each harbor utilized units of the same design and manufacture, and therefore the variation in degree of damage must be traced to other causes. These causes, undoubtedly, were: (a) the fact that the British beaches, being located so far to the eastward from the American beaches, are in the lee of the Fecamp coast line; (b) to the north and eastward of the British artificial harbor, is located the extensive area of shoal water (the Calvados shoal; discussion by Jellett, Institute of Civil Engineers, 1948, p. 333) caused by the Calvados Rock which provide, to a certain degree, the advantages of a protected harbor;..."

Seiwell (1947, p. 206) states:

"Thus, wave heights as occurred during June 1944 in the English Channel were not unique, and had been recorded for this same season of other years.

[1] References cited in this appendix are listed in the References at the end of the main text.

Information of this kind was summarized and disseminated in a report on the Military Oceanography of the Channel Coast of France, by the Army Air Forces Oceanographic Section, in 1942 and 1943[4]. In this paper it was shown that in the area, of what later became the American and British invasion beaches, between Le Harve and Cherbourg, wave heights in excess of 8 feet had an occurrence expectancy of approximately 5 percent during the month of June. Thus, while seas of this magnitude are not the usual rule for June, the probability of occurrence was sufficiently high to have been considered in the design of a project as momentous as the Normandy artificial harbors, if the designers had been cognizant of the situation. The resulting destruction, and consequent cost in human life and equipment is but one of the instances where inclusion of relevant oceanographic data into an operational plan would have been a means of lessening, if not avoiding, a disaster."

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Coastal engineering is required for military ports and harbors and across-the-beach amphibious operations. Examples are given for operations during World War II, the Korean War, and the Vietnam Conflict, one very large (Normandy, France), and some small. Examples are provided to illustrate that no two beach operations are ever the same and that the effects of nature (storms and swell even in the absence of local storms) are often as important or even more important than enemy action. Both functional and structural design for planning and operations are needed. Past military operations have required coastal data and the development of coastal science and engineering in subject areas such as tidal/current analysis, wave/surf forecasting, surf characteristic estimation (including breaker type), surf effects on amphibious craft, beach characteristic estimation (onshore and nearshore profile, sediments), wave runup and bachwash on beaches, littoral current estimation (including alongshore and rip currents), processes at harbor entrances, beach trafficability, wave diffraction at breakwaters, and wave-induced forces. Some of this is described in context with operational needs. The need for reliable coastal intelligence information is emphasized. Thirty-six illustrations and 68 references are given.

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